Construction Planning, Equipment, and Methods

Sixth Edition

# MACHINE POWER

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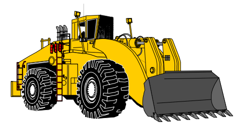

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**ENCE 420 – Construction Equipment and Methods**

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## INTRODUCTION

- The constructor must select the proper equipment to relocate and/or process materials economically.
- The decision process for matching the best possible machine to the project task requires consideration of the mechanical capabilities of the machine.

# INTRODUCTION

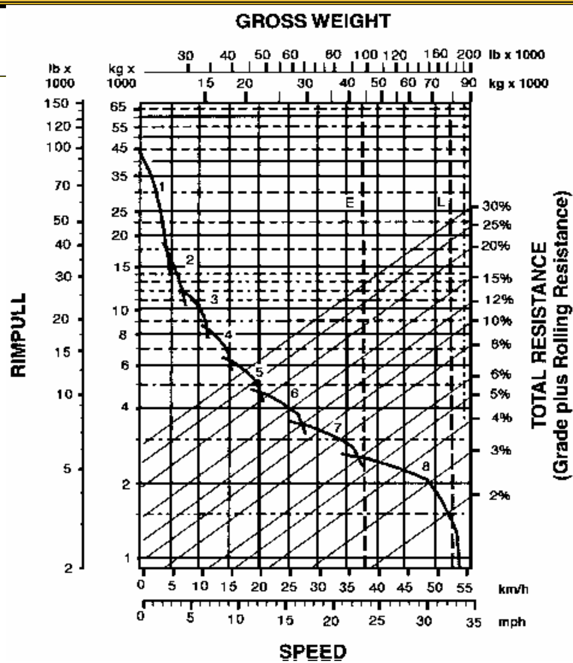
- The power is the power needed to propel the machine, and this power is established by two factors:
  1. **Rolling Resistance, and**
  2. **Grade Resistance.**



# INTRODUCTION

- Equipment manufacturers publish ***performance charts*** for individual machine models.
- These charts enable the equipment planner to analyze a machine's ability to perform under a set of job and load conditions.

# Performance Chart






# INTRODUCTION

- On heavy construction projects the major portion of the work consists of handling and processing bulk materials.
- The constructor must select the proper equipment to relocate and/or process materials economically.

# INTRODUCTION

- The decision process for matching the best possible machine to the project task requires that the contractor takes into account the following items:
  1. **Properties of the material to be handled (Chapter 4).**
  2. **Mechanical capabilities of the machine.**



# INTRODUCTION

- When estimator considers a construction material-handling problem, there are two primary material considerations:
  1) **Total quantity.**
  2) **Size of individual pieces.**

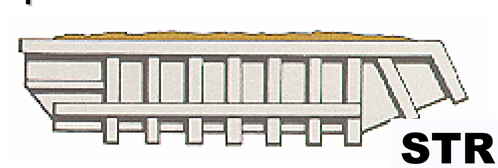
# PAYLOAD

- The payload of hauling equipment may be expressed either gravimetrically or volumetrically.
- Volumetric capacity can be stated as struck measure or in terms of:
  - ✓ **loose cubic yard (lcy),**
  - ✓ **bank cubic yard (bcy), or**
  - ✓ **compacted cubic yard (ccy).**



# STRUCK CAPACITY

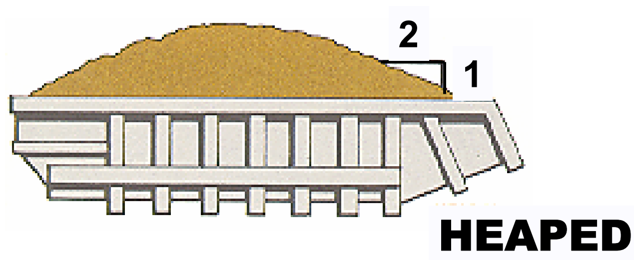
- Manufacturer's specification sheets will list both struck and heaped capacities.



**STRUCK**

**- material measured straight across the top of the body.**

# HEAPED CAPACITY




- based on a 2:1 slope above hauler bodies.



# PAYLOAD

- The payload capacity of a hauling unit is often stated by the manufacturer in terms of the volume of loose material that the unit can hold, assuming that the material is heaped in some specified angle of repose.

# PAYLOAD

- A gravimetric capacity would represent the safe operational weight that the axles and structural frame of the machine were designed to handle.



# MACHINE POWER

"Why does a machine only travel at 10 mph when its top speed is 30 mph?" This is a critical question because:

- Speed affects cycle time
- Cycle time drives production
- Production determines cost

# MACHINE PERFORMANCE

- To answer the travel speed question, it is necessary to analyze machine power.
- There are three power questions that need to be analyzed:
  1) **Required power.**
  2) **Available power.**
  3) **Usable power.**



# POWER REQUIRED

- A machine must overcome the forces of rolling and grade resistance to propel itself. These can be expressed as:
  - ✓ lb/ton
  - ✓ % effective grade

# POWER REQUIRED

- Two factors establish the power requirements:
  - ✓Rolling Resistance
  - ✓Grade Resistance
- Therefore, power required is the power necessary to overcome the total resistance to machine movement.



# POWER REQUIRED

- Total Resistance

Total Resistance (TR) =

Rolling Resistance (RR)
+
Grade Resistance (GR) **(1)**



# POWER REQUIRED

$$TR = RR + GR$$

# ROLLING RESISTANCE

- Rolling resistance is a measure of the force (lb/ton) that must be overcome to rotate a wheel over the surface on which it makes contact.



# ROLLING RESISTANCE

Rolling resistance is caused by

- Tire penetrating the surface

- Internal gear friction
- Tire flexing

# ROLLING RESISTANCE

- General Notes
  - ✓Rolling resistance (wheel resistance or track resistance) is the resistance of a level surface to constant-velocity motion across it.
  - ✓This resistance varies considerably with the type and condition of the surface over which a vehicle moves.



# ROLLING RESISTANCE

- General Notes (cont'd)
  - ✓For vehicles which move on rubber tires the rolling resistance varies with the size of, pressure on, and tread design of the tires.
  - ✓For equipment which moves on crawler tracks, such as tractors, the resistance varies primarily with the type and condition of the road surface.

# ROLLING RESISTANCE

- General Notes (cont'd)
  - ✓A narrow-tread, high-pressure tire gives lower rolling resistance than a broad-tread, low-pressure tire on a hard-surfaced road.
  - ✓If the road surface is soft and the tire tends to sink into the earth, a broad-tread, low-pressure tire will offer a lower rolling resistance than a narrow-tread, high-pressure tire.



# ROLLING RESISTANCE

- General Notes (cont'd)
  - ✓The maintenance of low-rolling-resistance haul roads is one of the best financial investments that an earth-moving contractor can make.

# ROLLING RESISTANCE

- Estimating Rolling Resistance
  - ✓Formulas
  - ✓Tables (general)
  - ✓Tow Cable Method



# ROLLING RESISTANCE

**If tire penetration is known**

**Rolling resistance (lb) =**

$$\left(40 + [30 + \mathrm{TP}]\right) \times \mathrm{GVW} \qquad (2)$$

- **TP = tire penetration, inches (may be different for haul and return)**
- **GVW = gross vehicle weight, tons**

# ROLLING RESISTANCE

If tire penetration is **not** known

Rolling Resistance (lb/ton) can be estimated from the information in Table 1

(Text Table 5.1)



# ROLLING RESISTANCE

**TABLE 5.1** | Representative rolling resistances for various types of wheels and surfaces*

| Type of surface | Steel tires, plain bearings | | Crawler type track and wheel | | Rubber tires, antifriction bearings | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | High pressure | | Low pressure | |
| | lb/ton | kg/m ton | lb/ton | kg/m ton | lb/ton | kg/m ton | lb/ton | kg/m ton |
| Smooth concrete | 40 | 20 | 55 | 27 | 35 | 18 | 45 | 23 |
| Good asphalt | 50–70 | 25–35 | 60–70 | 30–35 | 40–65 | 20–33 | 50–60 | 25–30 |
| Earth, compacted and maintained | 60–100 | 30–50 | 60–80 | 30–40 | 40–70 | 20–35 | 50–70 | 25–35 |
| Earth, poorly maintained | 100–150 | 50–75 | 80–110 | 40–55 | 100–140 | 50–70 | 70–100 | 35–50 |
| Earth, rutted, muddy, no maintenance | 200–250 | 100–125 | 140–180 | 70–90 | 180–220 | 90–110 | 150–200 | 75–100 |
| Loose sand and gravel | 280–320 | 140–160 | 160–200 | 80–100 | 260–290 | 130–145 | 220–260 | 110–130 |
| Earth, very muddy, rutted, soft | 350–400 | 175–200 | 200–240 | 100–120 | 300–400 | 150–200 | 280–340 | 140–170 |

*In pounds per ton or kilograms per metric ton of gross vehicle weight.

# ROLLING RESISTANCE

- Tow Cable Method
  - ✓Rolling resistance of a haul road can be approximated by towing a truck or other vehicle whose gross weight is known along a level section of the haul road at a uniform (constant) speed.



# ROLLING RESISTANCE

- Tow Cable Method (cont'd)
  - ✓The tow cable should be equipped with dynamometer or some other device which will permit determination of the average tension in the cable.
  - ✓This tension is the total resistance of the gross weight of the truck.

# ROLLING RESISTANCE

- **Tow Cable Method**

  **The rolling resistance in pounds per gross ton is given by**

$$R = \frac{P}{W} \quad (3)$$

Where

$R$ = rolling resistance in pounds per ton
$P$ = total tension in tow cable in pounds
$W$ = gross weight of truck in tons



# HAUL ROUTE

- Travel Distance
  - ✓Equipment selection is affected by travel distance because of the time factor it introduces into the production cycle.
  - ✓All other factors being equal, increased travel distances will favor the use of high-speed large capacity units.

# HAUL ROUTE

- Bearing Capacity
  - ✓A haul route must have sufficient bearing capacity to carry imposed loads.
  - ✓On low-bearing-capacity material, this may dictate the selection of track-type instead of wheel-type running gear.
  - ✓The use of special low-ground-pressure machines using wide tracks or balloon tires may be necessary.

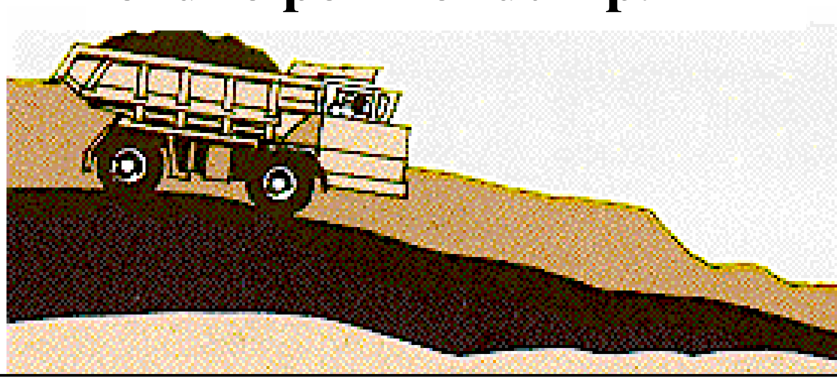


# HAUL ROAD CONDITION

**If haul roads are well maintained rolling resistance is less and production improves. Good haul roads require graders and water trucks, so there is a cost.**

# GRADE RESISTANCE

We seldom find a haul road which is level from point of load to point of dump.





# GRADE RESISTANCE

- Effect of Grade on Required Tractive Effort
  - The force-opposing movement of a vehicle up a frictionless slope is known as grade resistance.

# GRADE RESISTANCE

✓When a vehicle moves up a sloping road, the total tractive effort required to keep it moving increases approximately in proportion to the slope of the road.

- **If a vehicle moves down a sloping road, the total tractive effort required to keep it moving reduces approximately in proportion to the slope of the road.**

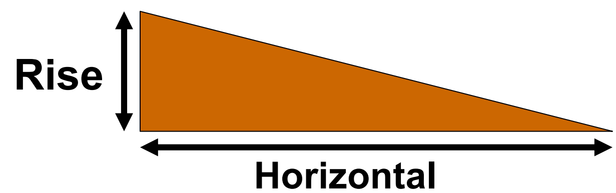


# GRADE RESISTANCE

- **The most common method of expressing a slope is by gradient in percent.**
- **A l% slope is one where the surface rises or drops 1 ft vertically in a horizontal distance of 100 ft. (1/100)**

# GRADE RESISTANCE

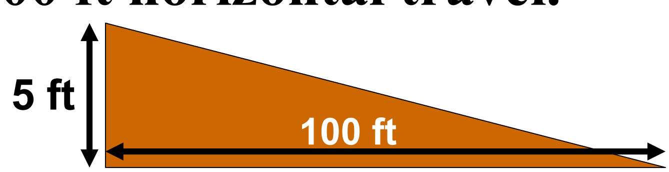
Grades are measured in % slope: the ratio between vertical rise (fall) and horizontal distance in which the rise/fall occurs.






# GRADE RESISTANCE

Grade example: 5 ft fall in 100 ft horizontal travel.




$$\frac{5\text{ ft}}{100\text{ ft}} \times 100 = 5\%$$

# GRADE RESISTANCE

- If the surface rises, the slope is defined as plus, whereas if it drops, the slope is defined as minus.
- For slopes of less than 10% (less than 10/100), the effect of grade is to increase, for a plus slope, or decrease, for a minus slope, the required tractive effort by 20 lb per gross ton of weight for each 1% of grade.



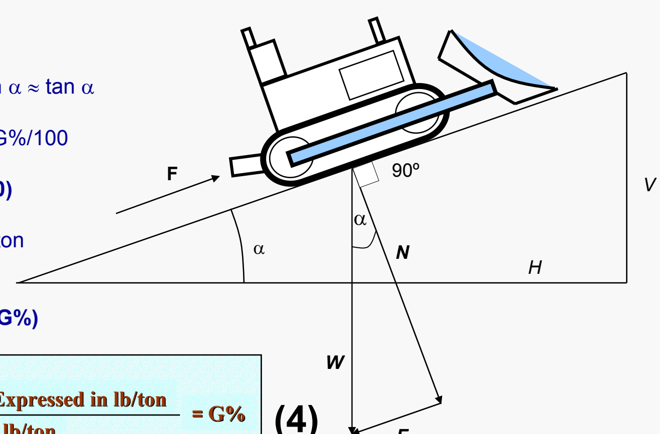
# FRICTIONLESS SLOPE-FORCE RELATIONSHIPS

$F = W \sin \alpha$
$N = W \cos \alpha$

for $\alpha < 10°$, $\sin \alpha \approx \tan \alpha$
$F = W \tan \alpha$
$\tan \alpha = V/H = G\%/100$
G% = gradient
$F = W\,(G\%/100)$

if $W = 2000$ lb/ton
and $G < 10°$

$F = 20$ lb/ton (G%)




$$\frac{\text{Rolling Resistance Expressed in lb/ton}}{\text{20 lb/ton}} = G\% \quad (4)$$

# EFFECT OF GRADE ON THE TRACTIVE EFFORT OF VEHICLES

## Table 2

| Slope (%) | lb/ton | kg/m ton | Slope (%) | lb/ton | kg/m ton |
|---|---|---|---|---|---|
| 1 | 20.0 | 10.0 | 12 | 238.4 | 119.2 |
| 2 | 40.0 | 20.0 | 13 | 257.8 | 128.9 |
| 3 | 60.0 | 30.0 | 14 | 277.4 | 138.7 |
| 4 | 80.0 | 40.0 | 15 | 296.6 | 148.3 |
| 5 | 100.0 | 50.0 | 20 | 392.3 | 196.1 |
| 6 | 119.8 | 59.9 | 25 | 485.2 | 242.6 |
| 7 | 139.8 | 69.9 | 30 | 574.7 | 287.3 |
| 8 | 159.2 | 79.6 | 35 | 660.6 | 330.3 |
| 9 | 179.2 | 89.6 | 40 | 742.8 | 371.4 |
| 10 | 199.0 | 99.5 | 45 | 820.8 | 410.4 |
| 11 | 218.0 | 109.0 | 50 | 894.4 | 447.2 |



# GRADE RESISTANCE

You need to review the derivation of equation 4. What it tells us is that for small angles (% grade) :

$$GR = 20 \text{ lb/tn} \times \% \text{ grade} \quad (5)$$

# GRADE RESISTANCE

Example: A truck with a 23 tn GVW is moving up a 4% grade. What is the force required to overcome grade resistance?

GR = 20 lb/tn × 23 tn × 4% grade

GR = 1,840 lb



# GRADE ASISTANCE

Gravity assists the machine when traveling down grade.

That force is referred to as **grade assistance.**

# GRADE ASISTANCE

Example: Our truck has dumped its load, the GVW is now 12 tn and on the return it is moving down the 4% grade. What is the force required to overcome grade resistance?

GA = 20 lb/tn x 12 tn x -4% grade

GA = -960 lb



# TOTAL RESISTANCE

Total Resistance =
Rolling Resistance +
Grade Resistance

TR = RR + GR or

TR = RR- GA

# Example 1

- The haul road from the borrow pit to the fill has an adverse grade of 4%. Wheel-type hauling units will be used on the job and it is expected that the haul road rolling resistance will be 100 lb/ton. **What will be the effective grade for the haul cycle? Will the units experience the same effective grade for the return cycle?**



# Example 1 (cont'd)

$$\text{Equivalent grade (RR)} = \frac{100 \text{ lb/ton rolling resistance}}{20 \text{ lb/ton}} = 5\%$$

**Effective grade (haul) = 5% RR + 4% GR = 9%**

**Effective grade (return)= 5% RR - 4% GR = 1%**

**RR = rolling resistance**

**GR = grade resistance**

# THE EFFECT OF GRADE ON LOCATING HAUL ROUTES

- During the life of a project the haul-route grades (and, therefore, grade resistance) may remain constant.
  - ✓**Example:** Hauling trucking aggregate from a rail-yard off-load point to the concrete batch plant.



# THE EFFECT OF GRADE ON LOCATING HAUL ROUTES

- In most cases, the haul-route grades change as the project progresses.
  - ✓**Example:** On a linear highway project, the top of the hills are cut and hauled to the valleys. Early in the project, the grades are steep and reflect the existing natural ground. Over the life of the project the grades begin to assume the final highway profile.

# THE EFFECT OF GRADE ON LOCATING HAUL ROUTES

- When the haul-route grades change, the estimator must first study the project's mass diagram to determine the direction that the material has to be moved. Then the natural ground and the final profiles depicted on the plans must be checked to determine the grades that the equipment will encounter during haul and return cycles.



# THE EFFECT OF GRADE ON LOCATING HAUL ROUTES

- The process of laying out haul routes is critical to machine productivity. If a route can be found which results in less grade resistance, machine travel speed can be increased and production will likewise increase.

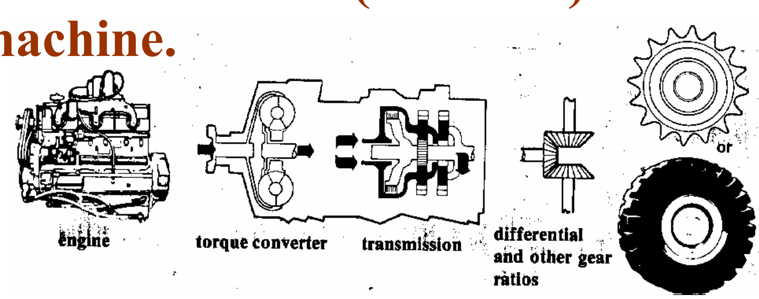
# THE EFFECT OF GRADE ON LOCATING HAUL ROUTES

- In planning a project, a constructor should always check several haul-route options before deciding on a final construction plan.



# AVAILABLE POWER

Engine horsepower and operating gear are the primary factors that determine the power available at the drive wheels (drawbar) of a machine.



# AVAILABLE POWER

**Horsepower involves a rate of doing work.**

**One hp = 33,000 ft-lb per minute**

**Therefore, must consider speed at which the machine travels when exerting a given amount of "*pull*."**



# POWER TRANSMISSION

- Most construction equipment is powered by internal combustion engines.
- Diesel engines perform better under heavy duty applications than gasoline engines
- Diesel-powered machines are the workhorses of the construction industry.

# POWER TRANSMISSION

- The characteristics which control the performance differences of gasoline and diesel engines are:
  - ✓ ***Carburetor*** - Used on gasoline engines, is an efficient method of regulating fuel.
  - ✓ ***Injector*** - Used on diesel engines, is a better method of regulating fuel.
  - ✓ ***Ignition system***
    - Gasoline engines use spark-ignition
    - Diesel engine meters fuel and air for compression-ignition.



# POWER TRANSMISSION

- **Diesel engines have:**
  1) Longer service lives
  2) Lower fuel consumption
  3) Presents less of a fire hazard.

# POWER TRANSMISSION

- **The basic equation that governs the mechanics of energy transmission is expressed as**

$$T_g = F_p \times r \qquad (6)$$

$F_p$ = piston force developed by engine

$r$ = radius of crankshaft

$T_g$ = crankshaft torque



# POWER TRANSMISSION

- The output of the engine at the flywheel at rated revolutions per minute (rpm) can be expressed as a flywheel horsepower (fwhp). This output can be measured by either friction belt or brake, hence the names belt horsepower or brake horsepower (bhp).

$$\text{fwhp} = \frac{2\pi N_g F_p r}{33{,}000} = \frac{2\pi N_g T_g}{33{,}000} \qquad (7)$$

$N_g$ = speed, in rpm (revolutions per minute)

$F_p$ = piston force, lb

$r$ = crankshaft, radius in ft

$T_g$ = crankshaft torque, lb-ft

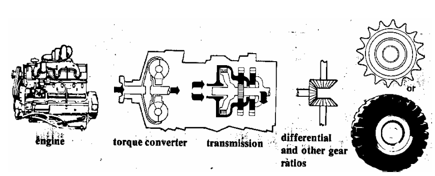
# POWER TRANSMISSION

- ***Flywheel horsepower*** is a standard rating used by equipment manufacturers to describe a machine's power. A manufacturer's flywheel horsepower rating is developed based on the engine turning at its rated rpm and driving all accessories normal to the machine's standard operational configuration.

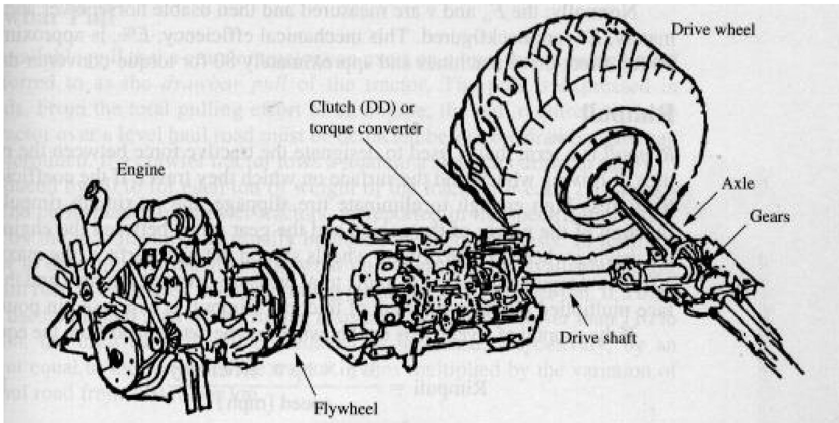


# POWER TRANSMISSION

- The power output from the engine, fwhp, becomes the power input to the transmission system. This system consists of the drive shaft, a transmission, planetary gears, drive axles, and drive wheels.



# POWER TRANSMISSION






# USABLE POWER

- **Rimpull**

  The usable power at the point of contact between the tire and the ground for a wheel machine.

# USABLE POWER

- **Drawbar Pull**

  The available usable power (pull) which a crawler tractor can exert on a load that is being towed.



# USABLE POWER

- The difference between rimpull and drawbar is a matter of convention; both rimpull and drawbar pull are measured in the same units, pounds pull.
- Both rimpull and drawbar pull are subject to adequate traction being developed.
- In the mechanical process of developing rimpull or drawbar pull there are power losses.

# USABLE POWER

- For any specified gear or speed-torque position on a torque converter

$$\text{Usable Horsepower} = \text{fwhp} \times \frac{E}{100} \qquad (8)$$

where $E$ (in %) is the efficiency of the power transmission.



# USABLE POWER

There are two methods for arriving at a machine's developed output force, $F_w$ (force at the wheel):

1. If the whole-body velocity ($v$) of the machine when operating at governed engine speed $N_g$ is known for a specific gear, the force at the wheel is given by

$$F_w = \frac{33{,}000 \times \text{fwhp} \times E}{v} \qquad (9)$$

where $v$ is the velocity in feet per minute, fpm.

# USABLE POWER

2. If the transmission gear ratio and the rolling radius of the wheel are known, *v* can be computed and then $F_w$ is determined. This assumes that there is no slippage in the gear train:

$$N(\text{drive axle}) = N_g \times \text{gear ratio} \quad (10)$$

where *N* for the drive axle is in rpm:

$$v = 2\pi \times R(\text{drive wheel}) \times N(\text{drive axle}) \quad (11)$$

where *R* (drive wheel) is the radius of the drive wheel.



# USABLE POWER

- Normally, the $F_w$ and *v* are measured and then usable horsepower and, ultimately, *E* are backfigured.
- This mechanical efficiency, *E*, is approximately 90 for direct drive machines and approximately 80 for torque-converter drives.

# COEFFICIENT OF TRACTION

- The total energy of an engine in any unit of equipment designed primarily for pulling a load can be converted into tractive effort only if *sufficient traction* can be developed between the driving wheels or tracks and the haul surface.
- If there is insufficient traction, the full power of the engine cannot be used, for the wheels or tracks will slip on the surface.



# COEFFICIENT OF TRACTION

- The coefficient of traction may be defined as:

**The factor by which the total load on a driving tire or track is multiplied in order to determine the maximum possible tractive force between the tire or track and the surface just before slippage occurs.**

**Usable force = (coefficient of traction) x (weight on powered running gear)** **(12)**

# COEFFICIENT OF TRACTION

| FOR TRUCK TYPE TRACTOR | FOR 4-WHEEL TRACTOR | FOR 2-WHEEL TRACTOR |
|---|---|---|
| The usual tractor weight | Use weight on drivers shown on spec sheet or approximately 40% of vehicle gross weight | Use weight on drivers shown on spec sheet or approximately 50% of vehicle gross weight |

| Surface | Rubber tires | Crawler tracks |
|---|---|---|
| Dry, rough concrete | 0.80-1.00 | 0.45 |
| Dry, clay loam | 0.50-0.70 | 0.90 |
| Wet, clay loam | 0.40-0.50 | 0.70 |
| Wet sand and gravel | 0.30-0.40 | 0.35 |
| Loose, dry sand | 0.20-0.30 | 0.30 |
| Dry snow | 0.20 | 0.15-0.35 |
| Ice | 0.10 | 0.10-0.25 |



# Example 2

- Assume that the rubber-tired tractor has a total weight of 18,000 lb on the two driving tires. The maximum rimpull in low gear is 9,000 lb. If the tractor is operating in wet sand, with a coefficient of traction of 0.30, the maximum possible rimpull prior to slippage of the tires will be

$$0.30 \times 18{,}000 \text{ lb} = \mathbf{5{,}400 \text{ lb}} < 9{,}000\text{lb}$$

- **Note:** Regardless of the power of the engine, not more than 5,400 lb of tractive effort can be used because of the slippage of the wheels.

# Example 2 (cont'd)

- If the same tractor is operating on dry clay, with a coefficient of traction of 0.60, the maximum possible rimpull prior to slippage of the tires will be

0.60 x 18,000 lb = 10,800 lb >9,000lb

- **Note:** For this surface the engine will not be able to cause the tires to slip. Thus, the full power of the engine can be used.



# Example 3

- A wheel-tractor scraper is used on a road project. When the project initially begins, the scraper will experience high rolling and grade resistance at one work area. The rimpull required to maneuver in this work area is 42,000 lb. In the fully loaded condition 52% of the total vehicle weight is on the drive wheels. The fully loaded vehicle weight is 230,880 lb. What minimum value of the

# Example 3 (cont'd)

of the coefficient of traction between the scraper wheels and the traveling surface is needed to maintain maximum possible travel speed?

**Weight on the drive wheels** = 0.52 x 230,880 lb = **120,058 lb**

**Minimum required coefficient of traction** = 42,000 lb/120,058 lb = **0.35**



# ALTITUDE EFFECT ON USABLE POWER

- Always remember that flywheel horsepower rating is based on tests conducted at standard conditions:

**Standard Conditions**

**At temperature of $60^0$ (F)**

**Sea level barometric pressure of 29.92 in (Hg)**

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# ALTITUDE EFFECT ON USABLE POWER

- For naturally aspirated engines operation at altitudes above sea level will cause a significant decrease in available engine power. This power decrease is caused by the decrease in air density associated with increased altitude.



ENCE 420 ©Assakkaf

# ALTITUDE EFFECT ON USABLE POWER

- ***Naturally aspirated engines:***
  - ✓ **Two-cycle diesel engine, reduce rated rimpull by 1.5% per 1,000 ft between sea level and 6,000 ft. Above 6,000 ft reduce rimpull by 3% per 1,000 ft.**
  - ✓ **Four-cycle gasoline and diesel engines- reduce rated rimpull by 3% for every 1,000 ft above 1,000 ft.**

# ALTITUDE EFFECT ON USABLE POWER

- ***Turbocharged engines:***
  - ✓ *Two- and four-cycle diesel engines -- usually very little or no loss in rated power up to 10,000 ft.*

***Turbocharger:*** a mechanical component mounted on the engine which forces air to the piston.



# Example 4

- Engines without turbocharger rely on the suction of the piston to supply the air for combustion. For a four-cycle engine with 100 fwhp at sea level, what is its usable power at 10,000 ft above sea level?

See Slide #84

$$\text{Sea-Level Power} \qquad = 100\text{ hp}$$

$$\text{Loss due to Altitude} = \frac{0.03 \times 100 \times (10{,}000 - 1000)}{10000} = -27\text{ hp}$$

$$\text{Usable Power} \qquad = 73\text{ hp}$$

# ALTITUDE EFFECT ON USABLE POWER

- A general formula for estimating purposes which expresses the effect of both temperature and altitude on four-cycle engines follows:

$$\text{Horsepower Available} = \text{rated hp} \times \frac{P_{\text{actual}}}{P_{\text{std}}}\sqrt{\frac{T_{\text{std}}}{T_{\text{actual}}}} \quad \textbf{(13)}$$

$P_{actual}$ = altitude at which the machine will be operated, in in. Hg (inches of mercury), barometric pressure
$P_{std}$ = standard condition altitude, usually sea level, 29.92 in. Hg
$T_{actual}$ = Rankine temperature at which the machine will be operated
$T_{std}$ = standard condition temperature, in Rankine units, usually 60ºF, which equals 520ºR



# ALTITUDE EFFECT ON USABLE POWER

- Average Barometric Pressures for Various Altitudes

**Table 1**

| Altitude above sea level (ft) | 0 | 1,000 | 2,000 | 3,000 | 4,000 | 5,000 |
|---|---|---|---|---|---|---|
| Barometric pressure (in. Hg) | 29.92 | 28.86 | 27.82 | 26.80 | 25.82 | 24.87 |

| Altitude above sea level (ft) | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 |
|---|---|---|---|---|---|
| Barometric pressure (in. Hg) | 23.95 | 23.07 | 22.21 | 21.36 | 20.55 |

# Example 5

- A tractor is powered by a four-cycle diesel engine. When tested under standard conditions, the engine developed 130 fwhp. What is the probable horsepower at altitude of 3,660 ft, where the average daily temperature is 720 F ?

$$\text{fwhp sts condition} = 130 \text{ hp}$$
$$P_{\text{std}} = 29.92 \text{ in Hg}$$
$$P_{\text{actual}} = 26.15 \text{ in Hg (form previous Table, by interpolation)}$$
$$T_{\text{std}} = 520^0 \text{R}$$
$$T_{\text{actual}} = 460 + 72 = 532^0 \text{R}$$

$$\text{fwhp} = \text{rated hp} \times \frac{P_{\text{actual}}}{P_{\text{std}}}\sqrt{\frac{T_{\text{std}}}{T_{\text{actual}}}} = 130\,\frac{26.15}{29.92}\sqrt{\frac{520}{532}} = 112.7 \text{ hp}$$



# RIMPULL

- Rimpull is a term which is used to designate the tractive force between the rubber tires of driving wheels and the surface on which they travel.
  - ✓ **If the coefficient of traction is high enough to eliminate tire slippage**, the maximum rimpull is a function of the power of the engine and the gear ratios between the engine and the driving wheels.

# RIMPULL

✓ **If the driving wheels slip on the haul surface**, the maximum effective rimpull will be equal to the total pressure between the tires and the surface multiplied by the coefficient of traction.



# RIMPULL

- **If the rimpull of a vehicle is not known**, it may be determined from the following equation:

$$\text{Rimpull} = \frac{377 \times \text{hp} \times E}{\text{speed (mph)}} (\text{lb}) \qquad (14)$$

# RIMPULL

- In computing the pull which a tractor can exert on a towed load, it is necessary to deduct from the rimpull of the tractor the tractive force required to overcome the rolling resistance plus any grade resistance for the tractor.



# Example 6

- The efficiency of most tractors and trucks will range from 0.8 to 0.85. For a rubber' d tractor with a 140-hp engine and a maximum speed of 3.25 mph in the first gear, tire the rimpull will be

Rimpull = [375 x 140 x 0.85]/3.25 = **13,730** lb

The maximum rimpull in all gear ranges for this tractor will be as follows:

| Gear | Speed (mph) | Rimpull (lb) |
|---|---|---|
| First | 3.25 | 13,730 |
| Second | 7.10 | 6,285 |
| Third | 12.48 | 3,576 |
| Fourth | 21.54 | 2,072 |
| Fifth | 33.86 | 1,319 |

# Example 7

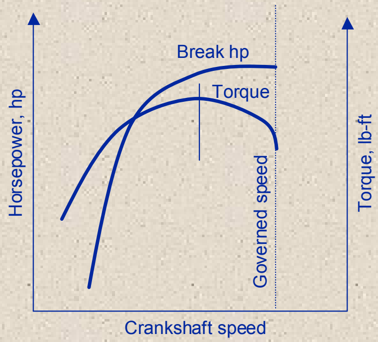
- If a tractor whose maximum rimpull in the first gear is13,730 lb, weighs 12.4 tons, and is operated up a haul road with a slope of 2% and a rolling resistance of 100 lb per ton, what is the available pull (lb) for towing a load?



# Example 7 (cont'd)

| | |
|---|---|
| Max rimpull | = 13,730 lb |
| Pull required to overcome grade, | |
| 12.4 ton x 20 lb/ton x 2% = 496 lb | |
| Pull required to overcome rolling resistance, | |
| 12.4 ton x 100 lb/ton = 1,240 lb | |
| Total pull to be deducted, 496 lb + 1,240 lb | = - 1,736 lb |
| **Pull available for towing a load** | **= 11,994 lb** |

# POWER OUTPUT AND TORQUE




Typical curves for **brake horsepower** (bhp) and **torque** as an engine increases its crankshaft speed to the governed rpm value. The important feature of this plot is the shape of the torque curve. **Maximum torque is not obtained at maximum rpm**. This provides the engine with a power reserve. When a machine is subjected to a momentary overload and this power is brought to bear, we "lug" the engine. The rpm drops but the torque goes up, keeping the engine from stalling under the overload.



# POWER OUTPUT AND TORQUE

- **Machines can be purchased with either a direct drive (standard) or a torque converter drive. With a direct-drive machine, the operator must manually shift gears to match the engine output to the resisting load. The difference in power available when considering maximum torque and torque at governed speed is the machine's operating range for a given gear.**

- ***A torque converter* is a device which adjusts power output to match the load.**

# PERFORMANCE CHARTS

- Performance charts for individual machine models are published by equipment manufacturers.
- These charts allow the equipment estimator/planner to analyze a machine's ability to perform under a given set of job and load conditions.



# PERFORMANCE CHARTS

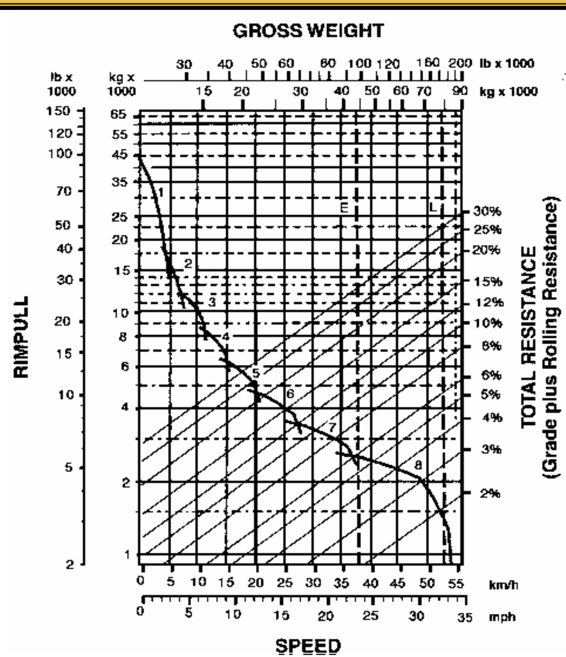
- The performance chart is a graphical representation of the power and corresponding speed that the engine and transmission can deliver.
- The load condition is stated as either rimpull or drawbar pull.

# PERFORMANCE CHARTS

- It should be noted that the rimpull-speed relationship is inverse since vehicle speed increases as rimpull decreases.
- If the gear ratios or rolling radius of a machine is changed, the entire performance curve will shift along both the rimpull and speed axles.



# POWER AVAILABLE

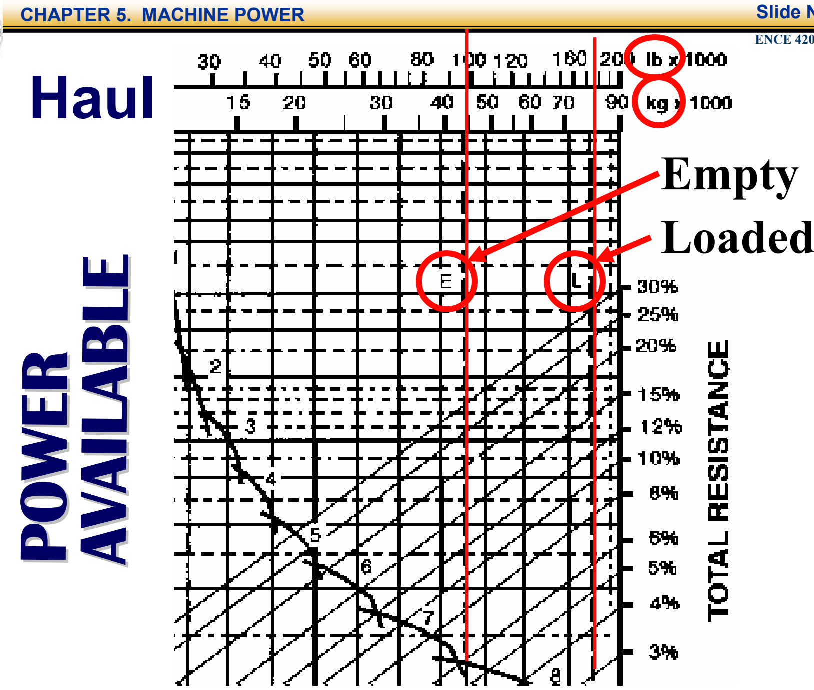


# PERFORMANCE CHARTS

| | | | |
|---|---|---|---|
| Engine: | flywheel power 450 | | |
| Transmission: semiautomatic power shift, eight speeds | | | |
| Capacity of scraper: | | Struck | - 21 cu yd |
| | | Heaped | - 31 cu yd |
| Weight distribution: | Empty | Drive axle | - 67% |
| | | Rear axle | - 33% |
| | Loaded | Drive axle | - 53% |
| | | Rear axle | - 47% |
| Operating weight: | Empty | | - 96,880 lb |
| Rated load: | | | - 75,000 lb |
| Top Speed: | Loaded | | - 33 mph |

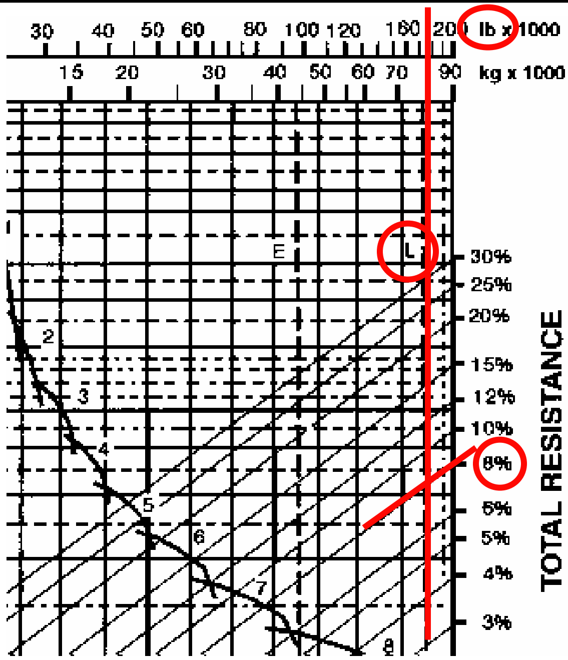


## Haul



# Haul

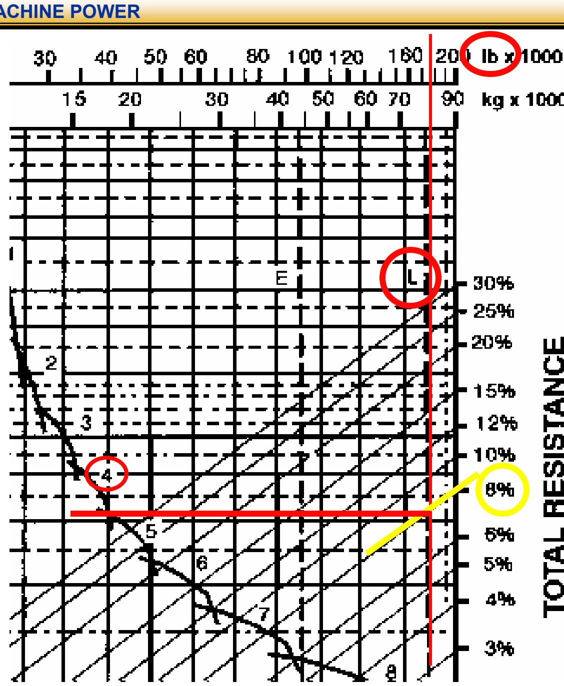
**POWER AVAILABLE**



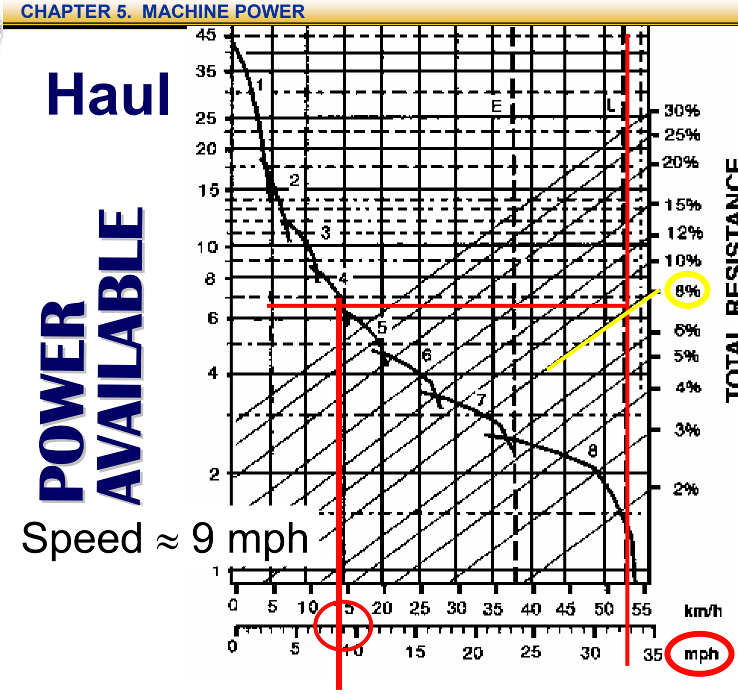



# Haul

**POWER AVAILABLE**

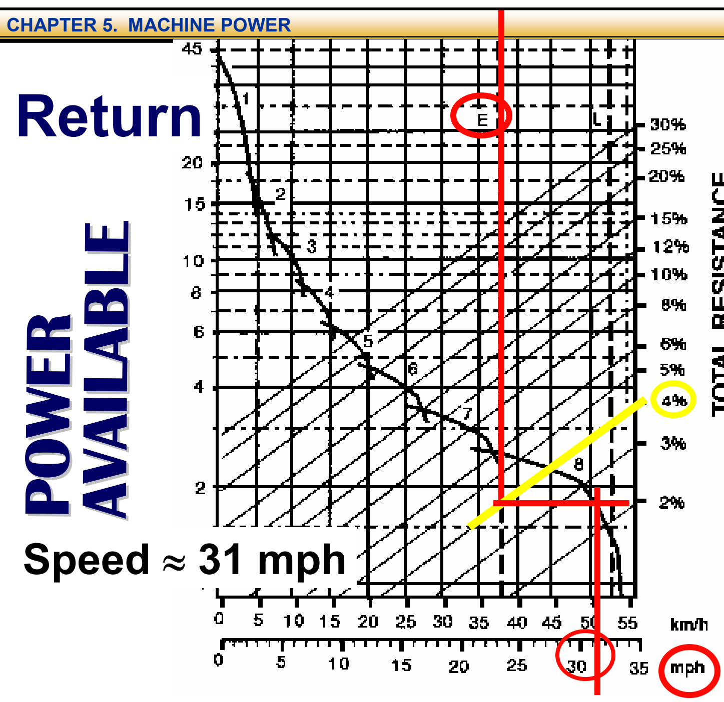


# Haul


POWER AVAILABLE
Speed ≈ 9 mph
TOTAL RESISTANCE
45
35
25
20
15
10
8
6
4
2
1
1
2
3
4
5
6
7
8
E
L
30%
25%
20%
15%
12%
10%
8%
6%
5%
4%
3%
2%
0 5 10 15 20 25 30 35 40 45 50 55
km/h
0 5 10 15 20 25 30 35
mph



# Return


POWER AVAILABLE
Speed ≈ 31 mph
TOTAL RESISTANCE
45
20
15
10
8
6
4
2
1
2
3
4
5
6
7
8
E
L
30%
25%
20%
15%
12%
10%
8%
6%
5%
4%
3%
2%
0 5 10 15 20 25 30 35 40 45 50 55
km/h
0 5 10 15 20 25 30 35
mph

# POWER AVAILABLE

**What if the total resistance is negative?**

**See Text page 146**

**Retarding Performance chart**

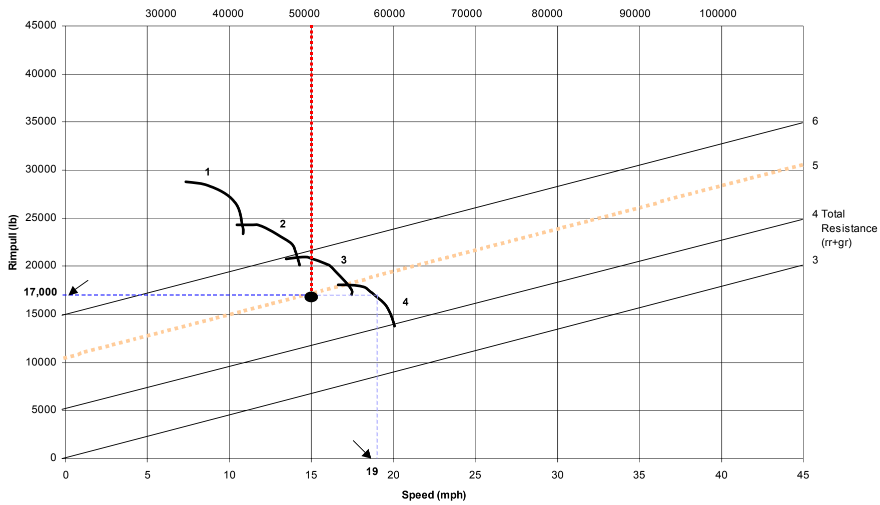
**The effective grade numbers are negative numbers.**



# PERFORMANCE CHARTS

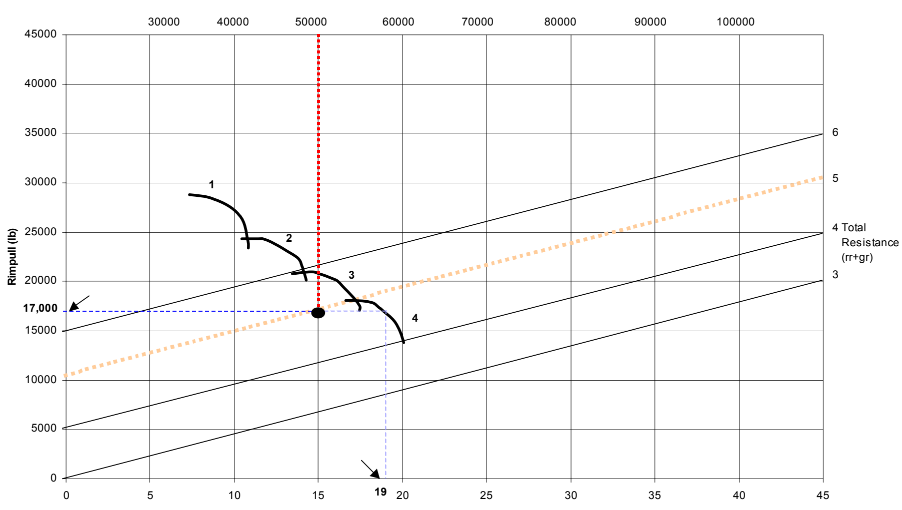
- **Example:** Reading Performance Chart
  - ✓The procedure for reading a performance chart is illustrated through an example.
  - ✓Assume that a scraper weighing 50,000 lb (gross weight) is operating uphill with an adverse slope of +3% and rolling resistance of 2%.

# PERFORMANCE CHARTS






# PERFORMANCE CHARTS



# PERFORMANCE CHARTS

- Here we have: RR+GR = 2+3 =5%. Referring to the chart, the intersection point (big black dot on the chart) of the weight vertical line with the total resistance inclined line establishes the condition.
- If we construct a horizontal line from this point and extend it to left, it will intersect the vertical rimpull scale at 17,000 lb, which is the rimpull for this scraper for this condition.



# PERFORMANCE CHARTS

- If we construct a horizontal line from this point (the big black dot) to the right, it will intersect the gear 4 curve.
- This means that the machine will be operating at this gear for the given condition.
- Finally, the speed of the scraper in this case is determined easily as follows:

# PERFORMANCE CHARTS

- From the intersection point of the gear 4 curve and the horizontal line extended from the big black dot, go vertically until the line intersects the horizontal speed scale.
- This should read a speed of 19 mph, which is the speed of the machine under the given condition.