Weight Transfer and Traction

Course 4171

Material in this lecture was taken from chapter 16 of Goreing, Engine and Tractor Power, 1992

Figure 16.1

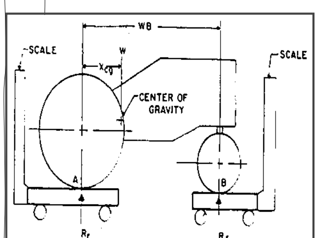


Figure 16.1–Tractor weight force and ground support forces.

Goreing, Engine and Tractor Power, 1992

- The center of gravity (*CG*) can be changed by adding a ballast.
  - A ballast ahead of *CG* increases X_{cg}
  - A ballast behind *CG* decreases X_{cg}
- Common ballast
  - Water with antifreeze in tire (25% air to absorb shock)
  - Rear wheel weights
  - Front end weights

Center of Gravity

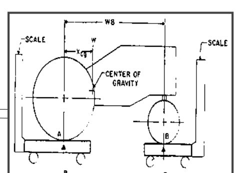


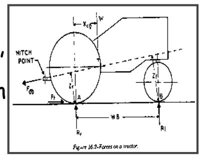
Figure 16.1–Tractor weight force and ground support forces.

Goreing, Engine and Tractor Power, 1992

- Taking moment at A
- $W * X_{cg} = R_f * W_B$
- Then, $X_{cg} = (R_f * W_B)/W$ (lbs*in)/lbs
  - Total weight known to be W
  - Front and rear wheel weight measured as Rf and Rb
    - W_b = wheel base
    - Xcg = center of gravity

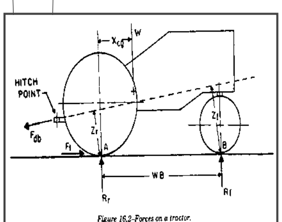
Weight Transfer

- Tractor can only produce drawbar load if ground provides a reaction force "Fc"
- The drawbar load F_{db} is shown at incline so Z_r and Z_f are different
- Choose moment about A
  - Change in front and rear wheel reactions as a result of drawbar load.



Goreing, Engine and Tractor Power, 1992

Figure 16.2



Goreing, Engine and Tractor Power, 1992

- $R_f * WB + F_{db} * Z_r = W * X_{cg}$
  - Solve for R_f (Dynamic front wheel reaction)
- $R_f = \frac{[(W * X_{cg}) - (F_{db} * Z_r)]}{WB}$
- Static front wheel reaction
  - Let $F_{db} = 0$ (no load)
- $R_{f0} = (W * X_{cg}) / WB$

Weight Transfer for Inclined F_{db}

- Front wheel: $\Delta R_f = R_{fo} - R_f = (F_{db} * Z_r) / WB$
- Rear wheel: $\Delta R_r = R_r - R_{ro} = (F_{db} * Z_f) / WB$
  - By choosing B as center of moment
  - For inclined load, the rear load increases more than the front load decreases
- For parallel load $Z_r = Z_f$, weight transfer > $\Delta R_f = \Delta R_r$
  - Note: front end reaction is decreased the same amount rear end is increased.

Tires

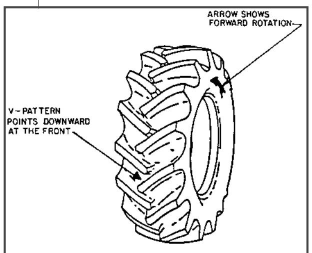


Figure 16.4—The tread pattern and direction of rotation of a tractor rear tire.

Goreing, Engine and Tractor Power, 1992

- Rear tires – lugged to develop traction
- Front tires – ribbed to improve steering
- Types
  - Biased-ply
  - Radial-ply

Types of tires

- Biased-ply
  - Less expensive
- Radial-ply
  - Lower pressure = more surface contact for better traction
  - Softer ride
  - More expensive
- Dual tires – add contact area, reduce compaction, increase stress

Traction

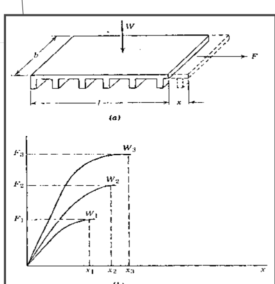


FIGURE 10-1 Method of determining maximum value of shearing force for various levels of vertical loading.

Liljedahl, Tractors and Their Power Units, 1996

- A = b*l (footprint)
- W = normal force
- Distance x is slip

Theoretical Model of Tractive Force

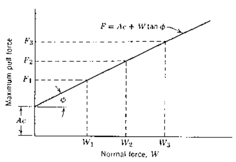


FIGURE 10-2 The soil parameters c and ϕ can be determined from a plot of maximum values of the shearing force F versus the normal force W.

- F = Ac + W tan ϕ
- F = A (c + p tan ϕ) [10.2]
  - A = b*l (footprint)
  - c = soil cohesion
  - W = normal force
  - ϕ = internation friction soil

Liljedahl, Tractors and Their Power Units, 1996

Traction con't

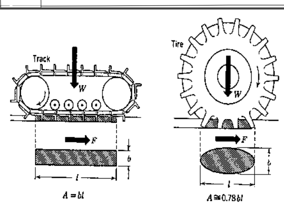


FIGURE 10-3 Soil thrust from a traction member is, in most cases, affected by both shear area and weight.

- Average soil pressure
  - P = W/(b*l)
- For tire
  - P = W/(.788*b*l)
- However, we seldom know c and ϕ, and p is not truly uniform.
  - Alternate methods are needed

Liljedahl, Tractors and Their Power Units, 1996

Definition

- A tractor can not develop drawbar power unless there is slip (travel reduction)
  - TR = 100 * [1 – (Sa/So)]
    - TR = travel reduction
    - Sa = Actual speed, mph
    - So = speed without load on specific surface
  - Slip = 1 – (Sa/So)
    - Same as TR, only fraction

Dynamic Traction Ratio

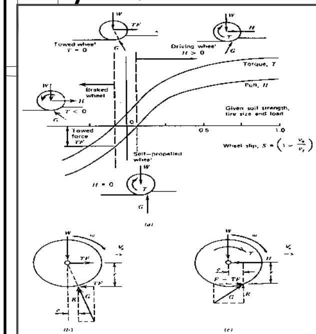


FIGURE 10-5 (a) Pull-torque-slip relation for wheels on soil. (b) Free-body diagram of a towed wheel. (c) Free-body diagram of a driving wheel.

Liljedahl, Tractors and Their Power Units, 1996

- Figure shows three states braked, driven and driving.
- Curves represent a given soil strength, tire size, and load. As soil strength increases it moves upward to the left, as it decreases it moves downward to the right.
- Pull and torque are plotted as a function of wheel slip.

Dynamic Traction Ratio

- Ratio of drawbar pull over dynamic weight on driving wheels
  - will be different for 2-wheel and 4-wheel drive
- 2-wheel:
  - $DTR2 = F_{db} / (R_{ro} + \Delta R_r)$
- 4-wheel:
  - $DTR4 = F_{db} / W$
    - F_{db} = drawbar pull (lbs)
    - R_{ro} = static Wt on rear wheel (lbs)
    - ΔR_r = Wt transfer to rear (lbs)

Tractive efficiency

- $TE = P_{db} / P_a$
  - Def: Fraction of axle power converted to drawbar power
  - P_{db} = drawbar power (HP)
  - P_a = Axle power (HP)
- $TE = (F_{db} * S_a) / (K_{lp} * P_a)$
  - K_{lp} = 3.6 SI ; 375 English
  - High TE achieved by adjusting ballast to optimize travel reduction

Figure 16.8

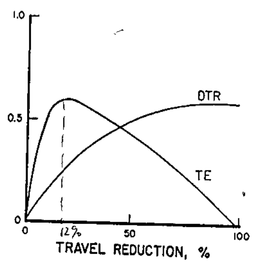


Figure 16.8–The variation of tractive efficiency and dynamic traction ratio with travel reduction on one specific soil.

Goering, Engine and Tractor Power, 1992

- DTR and TE vary with TR
- The TR at which peak TE occurs varies depending on track, 4WD, 2WD
- TR depends on and increases with F_{db}
- TR at peak TE is least for crawlers, vs highest for 2WD, with 4WD in between.

Tractive Performance and Weight Transfer by ZOZ

- ΔR_r = DWC * F_{db}

ΔR_r = weight transfer
F_{db} = drawbar force
DWC= dynamic wt. coefficient

- DWC = 0.65 for integral implements mounted to 3-pt hitch
  - Z_f and Z_r are impractical to measure in field
- DWC = 0.45 semi-mounted implement
- DWC = 0.20 implements on drawbar

Comments on ZOZ chart use

1. Common equations still apply
   - TR = [1 - (s_a/s_o)] * 100 **(travel reduction)**
   - TE = P_{db} / P_a (tractive efficiency)
   - P_{db} = (F_{db} * s_a) / 375 (drawbar power)
2. Most specifications are given on concrete track

Comments on ZOZ chart use

- Go to Nebraska tractor test to get vital information on the tractor being evaluated. Such as:
  1. SRAF- static rear axle force
  2. S_o -Travel speed with out load
  3. P_A - axle power

Nebraska Tractor Test Results

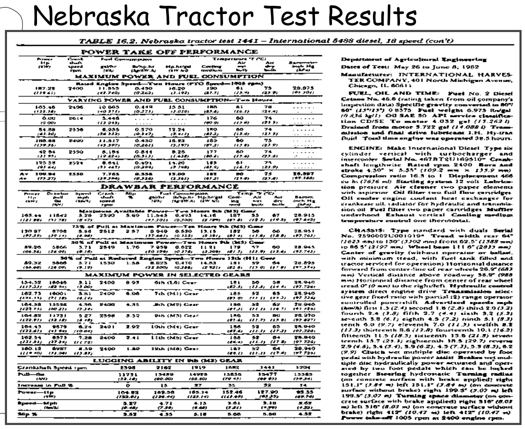


TABLE 16.2. Nebraska tractor test 1441 – International 5488 diesel, 18 speed (con't)

POWER TAKE OFF PERFORMANCE

Power Hp	Crank shaft speed rpm	Fuel gal/hr	lb/hp.hr	Hp.hr/gal	Temp. Cooling medium	Air wet bulb	Air dry bulb	Barometer inch Hg
MAXIMUM POWER AND FUEL CONSUMPTION								
Rated Engine Speed—Two Hours (PTO Speed—1005 rpm)								
187.22	2400	11.555	0.430	16.20	190	61	75	28.875
VARYING POWER AND FUEL CONSUMPTION—Two Hours								
165.46	2496	10.663	0.449	15.51	188	61	78	.....
0.00	2614	3.448	.....	.....	176	60	74	.....
84.88	2556	6.955	0.570	12.24	180	60	74	.....
186.88	2400	11.517	0.430	16.23	189	60	75	.....
42.84	2590	5.184	0.844	8.26	177	60	74	.....
125.38	2524	8.641	0.491	14.20	183	61	75	.....
Av 100.94	2550	7.765	0.558	13.00	182	60	75	28.897

DRAWBAR PERFORMANCE

Power Hp	Drawbar pull lbs	Speed mph	Crank shaft speed rpm	Slip %	gal/hr	lb/hp.hr	Hp.hr/gal	Cooling med	Air wet bulb	Air dry bulb	Barom. inch Hg
Maximum Available Power—Two Hours 9th (M3) Gear											
165.44	11842	5.24	2390	5.69	11.545	0.493	14.16	187	55	67	28.915
75% of Pull at Maximum Power—Ten Hours 9th (M3) Gear											
130.87	8796	5.58	2512	2.57	9.949	0.530	13.15	187	56	66	28.951
50% of Pull at Maximum Power—Two Hours 9th (M3) Gear											
89.26	5866	5.71	2549	1.76	7.959	0.622	11.21	179	57	60	28.945
50% of Pull at Reduced Engine Speed—Two Hours 13th (H1) Gear											
89.32	5866	5.71	1550	1.58	6.025	0.470	14.83	181	59	64	28.895

MAXIMUM POWER IN SELECTED GEARS

Power Hp	Drawbar pull lbs	Speed mph	Crank shaft speed rpm	Slip %	Gear	Cooling med	Air wet bulb	Air dry bulb	Barom. inch Hg
154.57	16046	3.11	2400	8.93	6th (L6) Gear	181	56	58	28.940
162.75	16001	3.81	2400	6.06	7th (M1) Gear	185	52	65	28.940
164.58	13536	4.56	2400	4.35	8th (M2) Gear	186	52	62	28.940
164.82	11731	5.27	2398	3.52	9th (M3) Gear	186	53	80	28.970
164.43	9879	6.24	2401	2.92	10th (M4) Gear	186	52	65	28.940
162.54	8373	7.28	2400	2.41	11th (M5) Gear	188	52	64	28.940
160.12	6907	8.59	2400	1.80	12th (M6) Gear	187	52	64	28.940

LUGGING ABILITY IN 9th (M3) GEAR

Crankshaft Speed rpm	2398	2162	1919	1682	1443	1204
Pull—lbs	11731	13489	14928	15838	15477	13385
Increase in Pull %	0	15	27	35	32	14
Power—Hp	164.82	169.58	165.14	152.46	127.90	95.55
Speed—Mph	5.27	4.71	4.15	3.61	3.10	2.68
Slip %	3.52	4.35	5.18	6.66	5.80	4.52

Department of Agricultural Engineering

Dates of Test: May 26 to June 8, 1982

Manufacturer: INTERNATIONAL HARVESTER COMPANY, 401 North Michigan Avenue, Chicago, IL 60611

FUEL, OIL AND TIME: Fuel No. 2 Diesel Cetane No. 46.6 (rating taken from oil company's inspection data) Specific gravity converted to 60°/60° (15°/15°) 0.8375 Fuel weight 6.973 lbs/gal (0.836 kg/l) Oil SAE 30 API service classification CD/SE To motor 4.032 gal (15.262 l) Drained from motor 3.722 gal (14.088 l) Transmission and final drive lubricant I.H. Hy-tran fluid Total time engine was operated 38.5 hours.

ENGINE: Make International Diesel Type six cylinder vertical with turbocharger and intercooler Serial No. 467BT2U189510* Crankshaft lengthwise Rated rpm 2400 Bore and stroke 4.30" × 5.35" (109.2 mm × 135.9 mm) Compression ratio 16.3 to 1 Displacement 466 cu in (7636 ml) Starting system 12 volt Lubrication pressure Air cleaner two paper elements with aspirator Oil filter two full flow cartridges Oil cooler engine coolant heat exchanger for crankcase oil, radiator for hydraulic and transmission oil Fuel filter two paper cartridges Muffler underhood Exhaust vertical Cooling medium temperature control one thermostat.

CHASSIS: Type standard with duals Serial No. 2590002U001019* Tread width rear 64" (1625 mm) to 130" (3302 mm) front 62.5" (1588 mm) to 86.5" (2197 mm) Wheel base 111.6" (2835 mm) Center of gravity (without operator or ballast, with minimum tread, with fuel tank filled and tractor serviced for operation) Horizontal distance forward from center-line of rear wheels 26.9" (683 mm) Vertical distance above roadway 38.9" (988 mm) Horizontal distance from center of rear wheel tread 0" (0 mm) to the right/left Hydraulic control system direct engine drive Transmission selective gear fixed ratio with partial (2) range operator controlled powershift Advertised speeds mph (km/h) first 1.5 (2.4) second 1.8 (2.8) third 2.0 (3.2) fourth 2.4 (3.8) fifth 2.7 (4.4) sixth 3.2 (5.2) seventh 3.8 (6.1) eighth 4.5 (7.2) ninth 5.1 (8.3) tenth 6.0 (9.7) eleventh 7.0 (11.3) twelfth 8.2 (13.3) thirteenth 8.6 (13.8) fourteenth 10.1 (16.2) fifteenth 11.5 (18.5) sixteenth 13.6 (21.8) seventeenth 14.7 (23.3) eighteenth 18.5 (29.7) reverse 2.9 (4.6), 3.4 (5.4), 3.9 (6.2), 4.5 (7.3), 5.3 (8.5), 6.2 (9.9) Clutch wet multiple disc operated by foot pedal with hydraulic power assist Brakes wet multiple disc hydraulically power actuated and operated by two foot pedals which can be locked together Steering hydrostatic Turning radius (on concrete surface with brake applied) right 151.1" (3.84 m) left 151.1" (3.84 m) (on concrete surface without brake) right 199.5" (5.07 m) left 199.5" (5.07 m) Turning space diameter (on concrete surface with brake applied) right 316" (8.03 m) left 316" (8.03 m) (on concrete surface without brake) right 412" (10.47 m) left 412" (10.47 m) Power take-off 1005 rpm at 2400 engine rpm.

Goreing, Engine and Tractor Power, 1992

ZOZ Chart

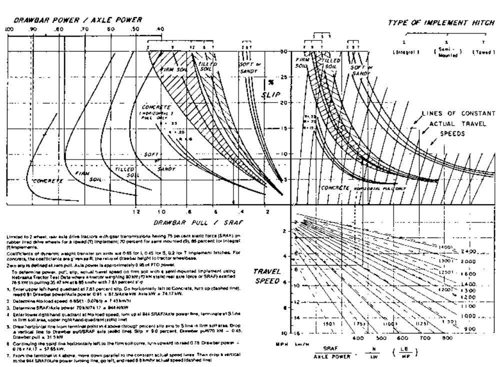


Figure 16.9–Traction prediction chart. (Reprinted from ASAE Data D230.4, Agricultural machinery management, revised December 1983.)

Goreing, Engine and Tractor Power, 1992

Comments on ZOZ chart use

3. If given the percent slip on concrete, enter at the slip in upper quadrant and go to the right to get TE and F_{db} / SRAF
4. Calculate S_o and SRAF / P_a, go to bottom right corner. Go up to speed curves, stopping at the right soil and hitch conditions. Follow lines of constant actual speed to get S_a.

Comments on ZOZ chart use

5. Go right to get the percent slip in soil condition
6. Turn down to get F_{db} / SRAF
7. Turn up to get TE

ZOZ Chart

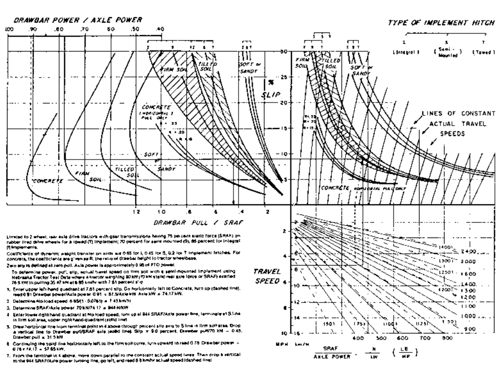


Figure 16.9–Traction prediction chart. (Reprinted from ASAE Data D230.4, Agricultural machinery management, revised December 1983.)

Goreing, Engine and Tractor Power, 1992

Rolling Resistance

- Force required to keep equipment moving at a constant speed
- Is proportional to equipment weight
- Coefficient of Rolling Resistance
  - $\rho = F_{draft} / W_{equip}$ (English)
  - $\rho = F_{draft} / (M_{equip} * 9.807(m/s^2))$ (SI)
- % slope = tan (angle soil surface and horizontal)

Example 1a:

- A tractor is pulling an 11,000 lb loaded wagon up a 10% slope at 6.2mph. The tractor weight is 6600 lbs.
  - Find the drawbar power if the coefficient of rolling resistance is 0.05 for all wheels.

Figure 2.3

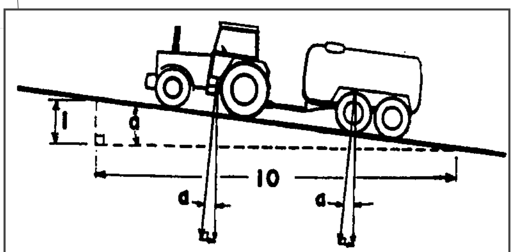


Fig. 2.3. Effects of weight on equipment moving up slope.

Hunt, Farm Power and Machinery Management, 2000

Example 1a con't:

1. Angle a = arctan (0.1) = 5.71°
2. Components of weight
   - Perpendicular to the slope
     - Wagon: 11,000 cos 5.71° = 10,945 lbs
     - Tractor: 6,600 cos 5.71° = 6567 lbs
   - Parallel to the slope
     - Wagon: 11,000 sin 5.71° = 1094.4 lbs
     - Tractor: 6600 sin 5.71° = 656.7 lbs

*

Example 1a con't:

3. Rolling resistance = ρ * wagon perpendicular
   - Wagon: 0.05 * 10945.42 = 547.25 lbs
4. Drawbar Pull = wagon parallel plus rolling resistance
   - F_{db} = 547.25 + 1094.43 = 1641.68 lbs
5. Drawbar power required
   - DBP = (1641.68 lbs * 6.2 mph) / 375 lbs*mph/HP = 27.14 HP