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

The center of gravity (CG) can be changed by adding a ballast.

1. A ballast ahead of CG increases \( X_{cg} \).
2. A ballast behind CG decreases \( X_{cg} \).

Common ballast:
1. Water with antifreeze in tire (25% air to absorb shock).
2. Rear wheel weights.
3. Front end weights.

Center of Gravity

- Taking moment at A
- \( W \times X_{cg} = R_f \times W_b \)
- Then, \( X_{cg} = \frac{(R_f \times W_b)}{W} \) (lbs*in)/lbs

- Total weight known to be W
- Front and rear wheel weight measured as \( R_f \) and \( R_b \)
- \( W_b = \) wheel base
- \( X_{cg} = \) 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.

Figure 16.2

- $R_f \cdot WB + F_{db} \cdot Z_r = W \cdot X_{cg}$
  - Solve for $R_f$ (Dynamic front wheel reaction)
- $R_f = \frac{(W \cdot X_{cg}) - (F_{db} \cdot Z_r)}{WB}$

Static front wheel reaction
- Let $F_{db} = 0$ (no load)
- $R_{f0} = \frac{(W \cdot X_{cg})}{WB}$

Weight Transfer for Inclined $F_{db}$

- Front wheel: $\Delta R_f = R_{f0} - R_f = \frac{(F_{db} \cdot Z_r)}{WB}$
- Rear wheel: $\Delta R_r = R_r - R_{ro} = \frac{(F_{db} \cdot Z_f)}{WB}$
  - 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

- 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

- $A = b^*l$ (footprint)
- $W = \text{normal force}$
- Distance $x$ is slip
**Theoretical Model of Tractive Force**

\[ F = A c + W \tan \phi \]

\[ F = A (c + p \tan \phi) \quad [10.2] \]

- \( A = b^* (\text{footprint}) \)
- \( c = \text{soil cohesion} \)
- \( W = \text{normal force} \)
- \( \phi = \text{interation friction soil} \)

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**Traction con't**

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

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**Definition**

- A tractor can not develop drawbar power unless there is slip (travel reduction)
  \[ TR = 100 \times [1 - (Sa/So)] \]

  - \( TR = \text{travel reduction} \)
  - \( Sa = \text{Actual speed, mph} \)
  - \( So = \text{speed without load on specific surface} \)
  - Slip = 1 - (Sa/So)

  - Same as TR, only fraction

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**Dynamic Traction Ratio**

- 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:
  \[ DTR_2 = \frac{F_{db}}{R_o + \Delta R_r} \]
- 4-wheel:
  \[ DTR_4 = \frac{F_{db}}{W} \]
  \[ F_{db} = \text{drawbar pull (lbs)} \]
  \[ R_o = \text{static Wt on rear wheel (lbs)} \]
  \[ \Delta R_r = \text{Wt transfer to rear (lbs)} \]

**Tractive efficiency**

- \[ TE = \frac{P_{db}}{P_a} \]
  - Def: Fraction of axle power converted to drawbar power.
  - \( P_{db} \) = drawbar power (HP)
  - \( P_a \) = Axle power (HP)
- \[ TE = \frac{(F_{db} \times S_o)}{(K_p \times P_a)} \]
  - \( K_p \) = 3.6 SI; 375 English
  - High TE achieved by adjusting ballast to optimize travel reduction.
Figure 16.8

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.

Goering, Engine and Tractor Power, 1992

Tractive Performance and Weight Transfer by ZOZ

\[ \Delta R_r = DWC \times F_{db} \]

- \( \Delta R_r \) = 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 = \( [1 - (s_o/s_a)] \times 100 \) (travel reduction)
   - TE = \( P_{db} / P_a \) (tractive efficiency)
   - \( P_{db} = (F_{db} \times s_o) / 375 \) (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
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 / $P_o$, 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 $S_o$.

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
Rolling Resistance

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

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.
Example 1a con't:

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

Example 1a con't:

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