Chapter 4
Tractors and Related Equipment

4. Tractor Uses:
Tractors have many uses as construction equipment. While their primary purpose may be to pull or push loads, they are also used as mounts for many types of accessories, such as front-end shovels, bulldozers and others. There are types and sizes to fit almost any job for which they are usable.

4.1. Types of Tractors:
In selecting a tractor several factors should be considered such as the following:

1. The size required for a given job.
2. The kind of job for which it will be used.
3. The type of footing over which it will operate.
4. The firmness of the haul road.
5. The smoothness of the haul road.
6. The slope of the haul road.
7. The length of the haul road.
8. Finally, the type of work it will do after this job is completed.

Tractors may be divided into two major types: Crawler Tractors and Wheel Tractors.

4.1.1. Crawler Tractors:
Crawler tractors are usually rated by size or weight and power. The weight is important on many projects because the maximum tractive effort that a unit can provide is limited to the product of weight times the coefficient of traction for the unit and the particular road surface, regardless of the power supplied by the engine. Most manufacturers make crawler tractors with some or all models
equipped with a choice of direct-drive or torque converter and power shift drives.

The equivalent drawbar pull which a crawler tractor must provide, regardless of whether it is a direct-drive or power-shift type, is the algebraic sum of the pull required by the towed load, the effect of grade on tractor and the effect of increased or decreased rolling resistance on the tractor.

\[
\text{Equivalent Drawbar Pull} = \left( \frac{\text{Pull Required by Towed Load}}{\pm \text{Effect of Grade}} \pm \text{Difference in Drawbar Pull due to Rolling Resistance} \right) 
\]

Example (4-1):
A crawler tractor must provide a drawbar pull of (5448 kg) to tow an attached load up a (6\%) grade over a haul road having a rolling resistance of (36 kg/ton). Determine the equivalent required drawbar pull for the tractor, if the weight of the tractor is (23.75 tons)

Solution:
The equivalent drawbar pull is as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Calculation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Drawbar pull required by towed load</td>
<td>5448.0</td>
</tr>
<tr>
<td>2.</td>
<td>Drawbar pull required by grade</td>
<td>1425.0</td>
</tr>
<tr>
<td>3.</td>
<td>Difference in drawbar pull</td>
<td>-332.5</td>
</tr>
</tbody>
</table>

The equivalent drawbar pull is = 6540.5 kg
4.1.2. Wheel Tractors:
Are either two-wheel or four-wheel. One of the primary advantages of a wheel tractor compared with a crawler tractor is the higher speed that may exceed (50 km/hr). However, in order to attain a higher speed a wheel tractor must sacrifice pulling effort. Also, because of lower coefficient of traction between rubber tires and soil surfaces, the wheel tractor may slip its wheels before developing its rated pulling effort.

The net drawbar pull of a wheel tractor is the **smaller value** obtained by either:

1. Deducing from the available rim pull the pull required to overcome the rolling resistance when it's traveling on a level haul surface.

\[
Net\ Drawbar\ Pull\ of\ a\ wheel\ tractor = \frac{Available\ Rim\ Pull - \text{Pull Required to overcome the Rolling Resistance}}{Resistance} \quad \ldots\ (4-2)
\]

2. Deducing from the product of the coefficient of traction and the gross weight on the pulling wheels the pull required to overcome the rolling resistance when it's traveling on a level haul surface.

\[
Net\ Drawbar\ Pull\ of\ a\ wheel\ tractor = (W_{on} \times \text{Coefficient of Traction} - \text{Rolling Resistance}) \quad \ldots\ (4-3)
\]

As the speed is increased through the selection of higher gear, the rim pull will be decreased in approximately the same proportion. Thus, for a given unit whose engine is operated at a rated power, the product of the speed times the rim pull will remain approximately constant.

4.2. Gradability:
Gradability is defined as the maximum slope (expressed as a percent) that a crawler or wheel-type tractor (or related equipment) may move up at a uniform speed.
The gradability may be determined for an empty or loaded vehicle, thus, the gradability for a tractor will be higher than for a tractor pulling a loaded vehicle. It may be specified for any desired gear.

The gradability of a crawler tractor is determined by subtracting from the available drawbar pull the total pull required to overcome the rolling resistance of the unit and any load that it will pull.

\[
\text{Gradability} = \frac{\text{Drawbar Pull to Overcome Grade}}{W_{\text{tons}} \times 10}
\]

\[
\left( \frac{\text{Drawbar Pull to Overcome Grade}}{W_{\text{tons}} \times 10} \right) = W_{\text{tons}} \times 10 \times \text{Gradability} \%
\]

**Note:**
In order to provide a reasonable factor of safety, not more than 85% of the rated drawbar pull of a tractor should be used in determining the gradability of the unit.

**Example (4-2):**
Determine the gradability of a crawler tractor pulling a high-pressure rubber-tired self-loading scraper and its load. The following information is available:

- Tractor horsepower, 180
- Drawbar pull in 1st gear, 15300 kg
- Weight of tractor, 20.25 tons
- Weight of loaded scraper, 39.48 tons
- Rolling resistance for tractor, 73 kg/ton
- Rolling resistance for scraper, 95 kg/ton
Solution:
The gradability is determined as follows:

\[
\begin{align*}
\text{Pull required for} & \quad \text{rolling resistance of tractor} \\
& = 20.25 \times (73 - 50) = 465.75 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Pull required for} & \quad \text{rolling resistance of scraper} \\
& = 39.48 \times 95 = 3750.6 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Combined pull required for} & \quad \text{rolling resistance} \\
& = 465.75 + 3750.6 = 4216.35 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Drawbar pull in } 1^{\text{st}} \text{ gear} & = 15300 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Maximum available (drawbar pull)} & = 0.85 \times 15300 = 13005 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Pull available for grade} & = \left( \text{Available drawbar pull} \right) - \left( \text{Pull required for rolling resistance} \right)
\end{align*}
\]

\[
\begin{align*}
\text{Pull available for grade} & = 13005 - 4216.35 = 8788.64 \text{ kg}
\end{align*}
\]

\[
\begin{align*}
\text{Combined weight for tractor and loaded scraper} & = 20.25 + 39.48 = 59.73 \text{ ton}
\end{align*}
\]

\[
\begin{align*}
\text{Gradability} & = \frac{\text{Drawbar Pull to Overcome Grade}}{W_{\text{tons}} \times 10} = \frac{8788.64}{59.73 \times 10} = 14.7\%
\end{align*}
\]
For the tractor alone the maximum gradability will be:

\[
\left(\frac{\text{Maximum available drawbar pull}}{\text{Pull required for rolling resistance of tractor}}\right) = 0.85 \times 15300 = 13005 \text{ kg}
\]

\[
\left(\frac{\text{Pull available for grade}}{\text{Drawbar Pull to Overcome Grade}}\right) = 13005 - 465.75 = 12539.25 \text{ kg}
\]

\[
\text{Gradability} = \frac{\text{Drawbar Pull to Overcome Grade}}{W_{\text{tons}} \times 10} = \frac{12539.25}{20.25 \times 10} = 61.9\%
\]

\[
\text{Gradability} = 62\%
\]

4.3. **Bulldozers:**

The term bulldozer may be used in a broad sense to include both a bulldozer and angledozer. These machines may be further divided, on the basis of their mountings, into crawler-tractor-mounted or wheel-tractor-mounted. A bulldozer may be classified (based on the method of raising and lowering the blade) as cable-controlled or hydraulically controlled.

4.3.1. **Uses of Bulldozers:**

1) Clearing land of timber.
2) Opening up roads through mountains and rocky areas.
3) Moving earth for haul distances up to approximately 100m.
4) Helping load tractor-pulled scrapers.
5) Spreading earth fill.
6) Clearing construction sites.
7) Maintaining haul roads.
4.3.2. Comparison between Bulldozers and Angledozers:

<table>
<thead>
<tr>
<th>Bulldozers</th>
<th>Angledozers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bulldozers are mounted with blades perpendicular to the direction of travel.</td>
<td>1. Angledozers are mounted with blades set at an angle with the direction of travel.</td>
</tr>
<tr>
<td>2. Bulldozers push the earth forward.</td>
<td>2. Angledozers push the earth forward and to one side.</td>
</tr>
</tbody>
</table>

* The size of a bulldozer is indicated by the length and height of the blade.

4.3.3. Advantages of Crawler-Mounted Bulldozers:

1) Ability to deliver greater tractive effort, especially in operating on soft footing, such as loose or muddy soil.
2) Ability to travel over muddy surfaces.
3) Ability to travel over rough surfaces, which may reduce the cost of maintenance.
4) Ability to operate in rocky formations, where rubber tires might be damaged.
5) Greater use on construction jobs.

4.3.4. Advantages of Wheel-Mounted Bulldozers:

1) Higher travel speed on the job or from one job to another.
2) Elimination of hauling equipment to transport the bulldozer to a job.
3) Greater output.
4) Less operator fatigue.
5) Ability to travel on paved highways without damaging the surface.
4.3.5. The Output of Bulldozers:
The blade of a bulldozer has a theoretical capacity which varies with the class of earth and size of the blade. If this capacity is known, then the approximate output of the machine may be determined by estimating the number of passes the machine will make in an hour.

Example (4-3):
Estimate the approximate output of a bulldozer for the following conditions:

- Swell, 25%.
- Haul distance, 30m.
- Moldboard size, 2.9m long, 0.9m high.
- Rated moldboard capacity, $2.5m^3$ loose volume.
- Operating factor, 50min/hr.
- Pushing speed, 2.4 km/hr.
- Returning speed, 4.8 km/hr.
- Fixed time, loading and shifting gears, 0.32 min.

Solution:
Net moldboard capacity = $2.5 + 1.25 = 2m^3$

Probable round-trip time:

Pushing, 30m, @ 2.4 km/hr,\[ \frac{30}{1000} \times \frac{60}{2.4} = 0.75 \text{ min} \]

Returning, 30m, @ 4.8 km/hr,\[ \frac{30}{1000} \times \frac{60}{4.8} = 0.375 \text{ min} \]

Fixed time, 0.32 min

Total time = 0.75 + 0.375 + 0.32 = 1.445 min

Trip per hour, $50 \div 1.445 = 34.6$

Output per hour, $34.6 \times 2 = 69.2 \text{ m}^3 / \text{hr}$
4.4. **Front-End Loaders:**

Front end loaders are used extensively in construction work to handle and transport bulk materials, such as earth and rock, to load trucks, to excavate earth, as bulldozers…etc. they are satisfactory and economical when used for such purposes. A wheel loader is shown in Fig. (4-1).

![Figure (4-1) – Front Wheel Loader in Operation](image)

4.4.1. **Types and Sizes:**

There are basically two types of front-end loaders, the crawler-tractor-mounted type and the wheel-tractor-mounted type. They may further be classified by the capacities of the buckets or the weight that the buckets can lift.

4.4.2. **Production Rates for Crawler-Tractor Loaders:**

The production rate for a tractor loader will depend on:

1. The fixed time required to load the bucket, shift gear, turn, and dump the load.
2. The time required to travel from the loading position to the dumping position.
3. The time required to return to the loading position.
4. The actual volume of material hauled each trip.

**Example (4-4):**

Find the production rate of the crawler-tractor-mounted loader shown in Figure (4-1), using the following information:
– Bucket capacity, 1.72 m³
– Swell, 25%
– Tractor operating factor, 45 min/hr
– Travel speed by gear:

<table>
<thead>
<tr>
<th></th>
<th>Forward Speed (m/min)</th>
<th>Reverse Speed (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>51</td>
<td>1st</td>
</tr>
<tr>
<td>2nd</td>
<td>78</td>
<td>2nd</td>
</tr>
<tr>
<td>3rd</td>
<td>107</td>
<td>3rd</td>
</tr>
</tbody>
</table>

Assume that the tractor will travel at an average of 80% of the specified speeds in 2nd gear, forward and reverse. The fixed time should be based on time studies for the particular equipment and job, for this example let it be (0.4 min).

Solution:
The cycle time per load will be, in minutes:

<table>
<thead>
<tr>
<th></th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed time (load, shift, turn and dump)</td>
<td>0.40</td>
</tr>
<tr>
<td>Haul time</td>
<td>( \frac{6 \times 2}{0.8 \times 78} = 0.19 )</td>
</tr>
<tr>
<td>Return time</td>
<td>( \frac{6 \times 2}{0.8 \times 97} = 0.16 )</td>
</tr>
</tbody>
</table>
Although the rated capacity of the bucket is (1.72 m³), it's probable that the average volume will be about 90% of this capacity for sustained loads.

\[
0.9 \times 1.72 = 1.55 \ m^3
\]

The material swell is 25% and the operating factor for the tractor is (45 min/hr)

Volume per hour in bank measure will be

\[
\frac{124}{1.25} \times \frac{45}{60} = 74.4 \ m^3/\text{hr}
\]

**The production rate will be 74.4 m³/hr**

### 4.4.3. Production Rates for Wheel-Tractor Loaders:

The production rates for wheel-tractor loaders are determined in the same manner as for crawler –tractor loaders. However, because they are more maneuverable and can travel faster on smooth haul surfaces, the production rates for wheel units should be higher than the crawler units under favorable conditions.

**Example (4-5):**

Resolve Ex. (4-4) using a wheel-tractor-mounted loader, which is equipped with a torque converter and a power-shift transmission, having the following speed ranges, forward and reverse:

<table>
<thead>
<tr>
<th>Speed Ranges, Forward and Reverse (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low range</td>
</tr>
<tr>
<td>intermediate range</td>
</tr>
<tr>
<td>high range</td>
</tr>
</tbody>
</table>
- When hauling a loaded bucket, the unit should travel at an average speed of about 80% of its maximum speed in the low range.
- When returning empty, the unit should travel at an average speed of about 60% of its maximum speed in the intermediate range for distances less than (30.5m), and at about 80% of its maximum speed in the same range for distances equal and more than (30.5m).

Solution:
At first the average speeds for hauling and returning must be calculated as shown below:

<table>
<thead>
<tr>
<th>Average speeds (m/min):</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>for Hauling, all distances</td>
<td>$0.8 \times \frac{6 \times 1000}{60} = 80$</td>
</tr>
<tr>
<td>for Returning, distances &lt;30.5m</td>
<td>$0.6 \times 18 \times \frac{1000}{60} = 180$</td>
</tr>
<tr>
<td>Returning, distances ≥30.5m</td>
<td>$0.8 \times 18 \times \frac{1000}{60} = 240$</td>
</tr>
</tbody>
</table>

The cycle time per load will be, in minutes:

<table>
<thead>
<tr>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed time (load, shift, turn and dump)</td>
</tr>
<tr>
<td>Haul time</td>
</tr>
<tr>
<td>Return time (distance=12m &lt;30.5m)</td>
</tr>
<tr>
<td>Cycle time (min)</td>
</tr>
</tbody>
</table>

The average volume will be about 90% of the rated capacity of the bucket ($1.72m^3$).

$$0.9 \times 1.72 = 1.55 \ m^3$$
No. of cycles \( \frac{60}{0.57} = 105.3 \)

Volume \( 105.3 \times 1.55 = 163.2 \text{ m}^3 \)

The material swell is 25% and the operating factor for the tractor is (45 min/hr)

Volume per hour in bank measure will be \( \frac{163.2}{1.25} \times \frac{45}{60} = 97.92 \text{ m}^3 / \text{hr} \)

**The production rate will be 97.92 m³/hr**

Compare this answer with the production rate for the crawler loader from the previous example; note that the rate is higher for wheel loaders than that of crawler loaders if both are operating for the same distances.

**Example (4-6):**

Find the production rate of the wheel-tractor-mounted loader, using the following information:

- Bucket capacity, 1.9 m³
- Loose volume of handling material, 1602 kg/m³
- Swell, 25%
- Tractor operating factor, 45 min/hr
- The unit is equipped with a torque converter and a power-shift transmission, having the following speed ranges, forward and reverse:

<table>
<thead>
<tr>
<th>speed ranges, forward and reverse (km/hr)</th>
<th>Low range</th>
<th>intermediate range</th>
<th>high range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low range</td>
<td>0-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>intermediate range</td>
<td>0-18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>high range</td>
<td>0-48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- When hauling a loaded bucket, the unit should travel at an average speed of about 80% of its maximum speed in the low range.
- When returning empty, the unit should travel at an average speed of about 60% of its maximum speed in the intermediate range for distances less than (30.5m), and at about 80% of its maximum speed in the same range for distances equal and more than (30.5m).
Solution:

Average speeds (m/min):

<table>
<thead>
<tr>
<th></th>
<th>for Hauling, all distances</th>
<th>$0.8 \times 6 \times \frac{1000}{60} = 80$</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>for Returning, distances &lt;30.5m</td>
<td>$0.6 \times 18 \times \frac{1000}{60} = 180$</td>
<td>180</td>
</tr>
<tr>
<td>Returning, distances ≥30.5m</td>
<td>$0.8 \times 18 \times \frac{1000}{60} = 240$</td>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>

The calculation of the haul and return times according to different distances would be as follows:

- For 7.5 m:
  
  Haul time, (min) = $\frac{7.5}{80} = 0.09 \text{ min}$
  
  Return time, (min) = $\frac{7.5}{180} = 0.04 \text{ min}$

- For 45 m:
  
  Haul time, (min) = $\frac{45}{80} = 0.56 \text{ min}$
  
  Return time, (min) = $\frac{45}{240} = 0.19 \text{ min}$

Cycle time for one-way distance:

<table>
<thead>
<tr>
<th>Haul distances, (m)</th>
<th>7.5</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed time, (min)</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Haul time, (min)</td>
<td>0.09</td>
<td>0.19</td>
<td>0.38</td>
<td>0.56</td>
<td>0.75</td>
</tr>
<tr>
<td>Return time, (min)</td>
<td>0.04</td>
<td>0.08</td>
<td>0.17</td>
<td>0.19</td>
<td>0.25</td>
</tr>
<tr>
<td>Total Cycle Time, (min)</td>
<td>0.48</td>
<td>0.62</td>
<td>0.90</td>
<td>1.10</td>
<td>1.35</td>
</tr>
<tr>
<td>Tractor operating factor, (min/hr)</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Trips per Hour</td>
<td>93.75</td>
<td>72.58</td>
<td>50.00</td>
<td>40.91</td>
<td>33.33</td>
</tr>
</tbody>
</table>

Volume hauled per hour, in m³ bank measure, by size of buckets:

<table>
<thead>
<tr>
<th>Size of Bucket, m³</th>
<th>One-Way Haul Distance, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trips per Hour</td>
<td>93.75</td>
</tr>
<tr>
<td>Loose Bank**</td>
<td>7.5</td>
</tr>
<tr>
<td>1.5</td>
<td>1.08</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
</tr>
<tr>
<td>2.5</td>
<td>1.80</td>
</tr>
<tr>
<td>3</td>
<td>2.16</td>
</tr>
<tr>
<td>3.5</td>
<td>2.52</td>
</tr>
</tbody>
</table>

* These values are based on a swell of (25%), and an average load equal to (90%) of the rated capacity of the buckets.

**HW:**

Find the production rate of the wheel-tractor-mounted loader, using the following information:

- Bucket capacity, 2.3 m³
- Loose volume of handling material, 1480kg/m³
- Swell, 20%
- Tractor operating factor, 52 min/hr
- The unit is equipped with a torque converter and a power-shift transmission, having the following speed ranges, forward and reverse:

<table>
<thead>
<tr>
<th>speed ranges, forward and reverse (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low range</td>
</tr>
<tr>
<td>intermediate range</td>
</tr>
<tr>
<td>high range</td>
</tr>
</tbody>
</table>

- When hauling a loaded bucket, the unit should travel at an average speed of about 80% of its maximum speed in the low range.
- When returning empty, the unit should travel at an average speed of about 40% of its maximum speed in the intermediate range for distances less than (40m), and at about 60% of its maximum speed in the same range for distances equal and more than (40m).
- The fixed time (load, shift, turn and dump) is equal to 0.35 min.

**Note:** Tabulate the results for two distances: 24m and 48m.