Chapter 3
Engineering Fundamental of Moving Earth

3. Engineering Fundamental of Moving Earth:

3.1. General Information:

In this chapter many problems related to excavation, hauling and placing earth will be discussed. With the constantly growing volume of earthwork for dams, highways, airports and other projects the need for selecting the most suitable construction equipment is becoming increasingly important. Persons in the construction industry, including contractors and engineers, should understand the effects which the selection of equipment and methods has on the cost of handling earth.

3.2. Rolling Resistance:

Rolling Resistance is a resistance which is encountered by a vehicle in moving over a road or surface. This resistance varies considerably with the type and condition of the surface over which a vehicle moves.

Soft earth offers a higher resistance than hard-surfaced roads such as concrete pavement.

For vehicles which move on rubber tires the rolling resistance varies with:

1. The size of tire.
2. The pressure of tire.
3. The tread design of tires.

For crawler equipment the rolling resistance varies with:

1. The type of road surface.
2. The condition of road surface.

Rolling resistance is expressed in kilograms of tractive pull required to move each gross ton over a level surface of the specified type or condition. For example, if a loaded truck having a gross weight equal to (20 tons) is moving over a level road whose rolling resistance is (45 kg/ton), the tractive effort required to keep the truck moving at a uniform speed will be:

$$20\ tons \times 45\ kg/ton = 900\ kg$$

Therefore, the tractive effort required to keep the truck moving at a uniform speed will be:

$$P = R \times W \qquad \ldots\ldots (3\text{-}1)$$

Where, P= tractive effort to pull truck, kg

R= rolling resistance, kg per ton

W= gross weight of truck, tons.

3.3. The Effect of Grade on Required Tractive Effort:

When a vehicle moves up a sloping road, the total tractive effort required to keep the vehicle moving is increased approximately in proportion to the slope of the road. While if the vehicle moves down a sloping road, the total tractive effort required to keep the vehicle moving is reduced in proportion to the slope of the road.

The effect of grade is to increase (for a plus slope), or decrease (for a minus slope), the required tractive effort by (10 kg/ton) of weight for each (1%) of grade. Fig. (3-1) illustrates the method of determining the effect of grade on tractive effort.

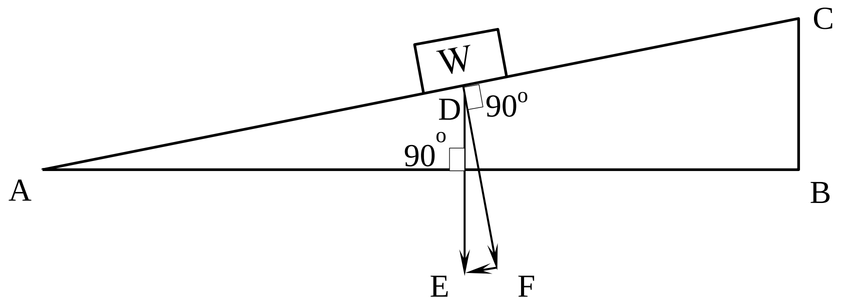

Fig. (3-1) – The Effect of Grade on the Performance of a Tractor or Truck

The line (AB) is horizontal. The slope (AC) is (1%). (DE) is perpendicular to (AB). (DF) is perpendicular to (AC). (EF) is parallel to (AC). Triangle (DEF) is similar to triangle (ABC), for practical purposes the length of (AC) is (100m). (W) is a (1 ton=1000 kg) weight, represented by the vector ($\vec{DE}$). P is the component of (W) parallel to (AC), represented by the vector ($\vec{EF}$). From similarity of triangles:

$$\frac{EF}{DE} = \frac{P}{W} = \frac{BC}{AC}$$

$$P = W \times \frac{BC}{AC} = 1000 \times \frac{1}{100} = 10 \ \ Kg / ton$$

Therefore, for any given slope the approximate value P in kilograms per ton is:

$$P(kg) = W(ton) \times 10\left(\frac{kg}{ton}\right) \times \% \ slope \qquad \text{...... (3-2)}$$

Example (3-1):
Find the effect of grade on the total tractive effort of a truck whose gross weight is (20 tons). The truck is moving up a road whose slope is (5%).

Solution:
The additional tractive effort resulting from the slope is:

$$P = 20 \times 10 \times 5 = 1000 \ kg$$

Example (3-2):
Find the effect of grade on the total tractive effort of a truck whose gross weight is (40 tons). The truck is moving up a road whose slope is (3%).

Solution:
The additional tractive effort resulting from the slope is:

$$P = 40 \times 10 \times 3 = 1200 \ kg$$

* If a tractor is towing a load, the combined gross weights of the tractor and its towed load should be used in determining the effect of grade.

3.4. The Effect of Grade in Locating a Borrow Pit:

Sometimes engineers and contractors do not give sufficient consideration to the grade or slope of the haul road in locating borrow pits.it is desirable, when possible, to locate a borrow pit at a higher elevation than the fill, in order that the slope down the road may help the loaded trucks or other hauling equipment by permitting them to carry larger loads or to travel at higher speeds. Since the vehicle will be empty when returning up the road from the fill to the borrow pit, the effect of the grade will be considerably less.

3.5. Coefficient of Traction:

The total energy of an engine in any unit of equipment designed primarily for pulling 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 not sufficient traction, the full power of the engine cannot be used, and the wheels or tracks will slip on the surface.
The coefficient of traction between rubber tires or crawler tracks and different surfaces is important to the operators of hauling units.

The coefficient of traction may be defined as the factor by which the total load on a driving tire or track should be multiplied in order to determine the maximum possible tractive force between the tire or track and the surface just before slipping will occur.
The coefficient of traction between rubber tires and road surface varies with the type of tread on the tires and with the road surface.
The coefficient of traction between crawler tracks and road surface varies with the design of the grouser and the road surface.

Example (3-3):
Assume that a rubber-tired tractor has a total weight of (18000 kg) on the two driving tires. The maximum rimpull in low gear is (9000 kg). If the tractor is operating in wet sand, with a coefficient of traction of (0.3):

1. Find the maximum possible rim pull prior to slippage of the tires.
2. Find the maximum possible rim pull prior to slippage of the tires, if the same tractor is operating on dry clay, with a coefficient of traction of (0.6).

Solution:

1. For wet sand, the maximum possible rim pull prior to slippage of the tires will be:
   $$0.3 \times 18000 = 5400 \ kg$$
   Regardless of the power of the engine, not more than 5400 kg of tractive effort may be used because of the slippage of the wheels.

2. For dry clay, the maximum possible rim pull prior to slippage of the tires will be:
   $$0.6 \times 18000 = 10800 \ kg$$
   For this surface the engine will not be able to cause the tires to slip. Thus, the full power of the engine may be used.

3.6. Drawbar Pull:

The available pull which a crawler tractor can exert on a load that is being towed is referred to as the drawbar pull of the tractor. The pull is expressed in kilograms. If the crawler tractor tows a load up a slope, then, its drawbar pull will be reduced by 10 Kg/ton for each 1% slope.

In testing a tractor to determine the maximum drawbar pull at each of the available speeds, the haul road is calculated to have a rolling resistance of (50 Kg/ton). If a tractor is used on a haul road whose rolling resistance is higher or lower than (50 Kg/ton), the drawbar pull will be **reduced** or **increased**, respectively, by an amount equal to the weight of the tractor in tons multiplied by the variation of the haul road from (50 Kg/ton).

$$\begin{matrix}\textit{Difference in}\\ \textit{Drawbar Pull}\end{matrix}\ (kg) = W_{tons} \times \left(R\ R_{road} - 50\right) \qquad \text{...... (3-3)}$$

$$\begin{pmatrix}\textit{Effective}\\ \textit{Drawbar Pull}\end{pmatrix} = \begin{pmatrix}\textit{Original}\\ \textit{Drawbar Pull}\end{pmatrix} - \begin{pmatrix}\textit{Difference}\\ \textit{in Drawbar Pull}\end{pmatrix} - \begin{pmatrix}\textit{Drawbar Pull to}\\ \textit{Overcome Grade}\end{pmatrix}$$

$$\begin{pmatrix}\textit{Effective}\\ \textit{Drawbar Pull}\end{pmatrix} = \begin{pmatrix}\textit{Original}\\ \textit{Drawbar Pull}\end{pmatrix} - \left[\begin{pmatrix}\textit{Difference}\\ \textit{in Drawbar Pull}\end{pmatrix} + \begin{pmatrix}\textit{Drawbar Pull to}\\ \textit{Overcome Grade}\end{pmatrix}\right] \qquad \text{...... (3-4)}$$

Example (3-4):

A crawler tractor whose weight is (15 tons) has a drawbar pull of (2000 kg) in sixth gear when operated on a level road having a rolling resistance of (50 kg/ton); if the same tractor is operated on another level road having a rolling resistance of (82 kg/ton) then:

1. Will the drawbar pull of the tractor be reduced or increased, find the effective drawbar pull?
2. If the road have a slope of (3%), what will the effective drawbar pull be, if the tractor moves:
   a) Up the road.
   b) Down the road.

Solution:

1. The drawbar pull will be reduced because the rolling resistance is higher than the tested road.

$$\textit{Drawbar Pull} = W_{tons} \times \left(R\ R_{road} - 50\right)$$

$$\begin{matrix}\textit{Difference}\\ \textit{Drawbar Pull}\end{matrix} = 15_{ton} \times \left(82 - 50\right)_{Kg/ton} = 480\ kg$$

$$\textit{Effective Drawbar Pull} = 2000 - 480 = 1520 kg$$

2. If the tractor was moving on a sloped road, then:

a) If the tractor was moving up the sloped road, the drawbar pull used to overcome the grade must be reduced from the original drawbar pull:

$$\begin{matrix} \textit{Drawbar Pull to} \\ \textit{Overcome Grade} \end{matrix} = W_{tons} \times 10 \times Slope = 15 \times 10 \times 3 = 450kg$$

$$Effective\ Drawbar\ Pull = 2000 - 480 - 450 = 1070kg$$

b) If the tractor was moving down the sloped road, then the drawbar pull will be added to the original drawbar pull:

$$\begin{matrix} \textit{Drawbar Pull to} \\ \textit{Overcome Grade} \end{matrix} = W_{tons} \times 10 \times Slope = 15 \times 10 \times (-3) = -450kg$$

$$Effective\ Drawbar\ Pull = 2000 - 480 - (-450) = 1970kg$$

Example (3-5):

A tractor whose weight is (15 tons) has a drawbar pull of (2000 kg) in sixth gear when operated on a level road having a rolling resistance of (50 kg/ton); if the same tractor is operated on another level road having a rolling resistance of (30 kg/ton) then:

1. Will the drawbar pull of the tractor be reduced or increased, find the effective drawbar pull?
2. If the road have a slope of (3%), what will the effective drawbar pull be, if the tractor moves:
   a) Up the road.
   b) Down the road.

Solution:

1. The drawbar pull will be increased because the rolling resistance is lower than the tested road.

$$\begin{matrix} \textit{Difference} \\ \textit{Drawbar Pull} \end{matrix} = W_{tons} \times (R\ R_{road} - 50) = 15_{ton} \times (30 - 50)_{kg/ton} = -300\ kg$$

$$Effective\ Drawbar\ Pull = 2000 - (-300) = 2300kg$$

2. If the tractor was moving on a sloped road, then:
   a) If the tractor was moving up the sloped road, the drawbar pull used to overcome the grade must be reduced from the original drawbar pull:

$$\begin{matrix} \textit{Drawbar Pull to} \\ \textit{Overcome Grade} \end{matrix} = W_{tons} \times 10 \times Slope$$

$$\begin{array}{l} \textit{Drawbar Pull to} \\ \textit{Overcome Grade} \end{array} = 15 \times 10 \times (+3) = 450kg$$

$$\textit{Effective Drawbar Pull} = 2000 - (-300) - 450 = 1850kg$$

b) If the tractor was moving down the sloped road, then the drawbar pull will be added to the original drawbar pull:

$$\begin{array}{l} \textit{Drawbar Pull to} \\ \textit{Overcome Grade} \end{array} = W_{tons} \times 10 \times Slope = 15 \times 10 \times (-3) = -450kg$$

$$\textit{Effective Drawbar Pull} = 2000 - (-300) - (-450) = 2750kg$$

Note:

The drawbar pull of a crawler tractor will vary indirectly with the speed of each gear; it is highest in the first gear and lowest in the top gear. Specification supplied by the manufacturer should give the maximum speed and drawbar pull for each of the several gears.

3.7. Rim Pull:

Rim pull 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. Rim pull is expressed in kilograms, and it may be determined from Eq. (3-5):

$$Rim\ Pull_{(kg)} = \frac{274 \times hp \times efficiency}{speed_{(km/hr)}} \qquad \text{…… (3-5)}$$

The efficiency of most tractors and trucks will range from 80% to 85%

$$\begin{array}{l} \textit{Rim Pull Available} \\ \textit{for Towing Loads} \end{array} = \begin{array}{l} \textit{Maximim} \\ \textit{Rim Pull} \end{array} - \left(\begin{array}{l} \textit{Pull Required} \\ \textit{to Overcome Grade} \end{array} + \begin{array}{l} \textit{Pull Required to} \\ \textit{Overcome Rolling} \\ \textit{Resistance} \end{array} \right) \qquad \text{..…. (3-6)}$$

Example (3-6):

A tractor whose weight is (12.4 tons) has a maximum rim pull in the first gear of (6228 kg), is operated up a haul road with a slope of (2%) and a rolling resistance of (45 kg/ton); determine the rim pull available for towing a load.

Solution:

The rim pull available for towing a load will be determined as follows:

Maximum rim pull= $6228\ kg$

Pull required to overcome grade= $12.4 \times 10 \times 2 = 248\ kg$

Pull required to overcome rolling resistance= $12.4 \times 45 = 558\ kg$

Total pull to be deducted= $248 + 558 = 806\ kg$

Pull available for towing a load= $6228 - 806 = 5422\ kg$

Example (3-7):

A wheel-type tractor with a (250 hp) engine weights (12.4 tons) has a maximum speed of (8Km/hr) in the first gear, is operated up a haul road with a slope of (2%) and a rolling resistance of (50 Kg/ton); determine the rim pull available for towing a load if the efficiency was 80%.

Solution:

The rim pull available for towing a load will be determined as follows:

$$Maximum\ Rim\ Pull_{(kg)} = \frac{274 \times hp \times efficiency}{speed_{(km/hr)}} = \frac{274 \times 250 \times 0.8}{8} = 6850kg$$

Pull required to overcome grade= $12.4 \times 10 \times 2 = 248\ kg$

Pull required to overcome rolling resistance= $12.4 \times 50 = 620\ kg$

Total pull to be deducted= $248 + 620 = 868\ kg$

Pull available for towing a load= $6850 - 868 = 5982\ kg$