Journal of Engineering and Development, Vol. 11, No. 1, March (2007) ISSN 1813-7822

Effect of Normal Pressure on Drawbar Pull of Tracked Vehicle on Soft Grounds

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Abstract

It is generally accepted that normal pressure beneath a track laying vehicle has great influence on the slip and the tractive effort developed by the vehicle. However, and for simplicity, most of the previous works assume uniform pressure underneath the track. Consequently values of experimental results were quiet different from those of the predicted theoretical values.

In this paper, emphasizes have been directed towards proper selection of vehicle configuration which is of almost importance. So, and as a result , different types of normal pressure underneath the track have been analyzed, ranging from constant , to uniform sinusoidal, and then to non uniform values. The magnitudes of drawbar pull for each type of pressure distribution on soft ground were evaluated theoretically with the aid of computer, using ("MATLAB" package). The aim is to obtain the best value of draw-bar pull among these pressure distributions, thus achieving the optimum design criteria.

الخلاصـــــــة

من البديهي ان نمط توزيع الضغط الارضـي تحت المجنـزرة لـه تـاثير مهم علـى الانـزلاق و قـوة الدفع من قبل جنزير المركبة ، ولكن في معظم الابحاث السابقة ولغرض التبسيط، كان يفترض ثبوت الضغط تحت الجنزير ، وبالتـالي فان النتائج العملية غالبا ما تكون مخالفة للنتائج النظرية المتوقعة.

في هذا البحث اخذ بنظر الاعتبار اشكال مختلفة من توزيع الضغوط العمودية تحت الجنزير حيث تتراوح هذه القيم بين قيم ثابتة وقيم منتظمة موجية واخرى غير منتظمة وتم حساب قوة السحب للمجنـزرة علـى اراضـي صحراوية رملية باستخدام الحاسبة وبمساعدة (برنامج ماتلاب) والغاية من هذا البحث هو ايجاد افضل قوة للسحب بغية معرفة النمط الامثل من الضغط العمودي لتصميم المركبة المطلوبة.

1. Introduction

In cross-country operation, there are various types of terrain with differing characteristics, ranging from desert sand to deep mud to snow. The mechanical properties of the terrain quite often impose severe limitations to the mobility and performance of cross-country vehicles [1].

An adequate knowledge of the mechanical properties of the terrain and an understanding of the mechanics of vehicle-terrain interaction are therefore essential for the proper design, selection, and operation of the off-road vehicles. The study of the relationship between the performance of an off-road vehicle and its physical environment (terrain) has become an essential procedure for vehicle design.

A review of the theories of elastic and plastic behavior of the terrain that covers most of the trafficable earth surface had been presented by Bekker [2]. Application of these theories to the solutions of some of the problems in terramechanics will be discussed. These theories provide bases for the understanding of the physical nature of vehicle-terrain interaction. However, complete theories have not yet been fully developed to the point that will permit vehicle-terrain relationships to be accurately defined in the field. To provide a practical engineering approach to the evaluation and prediction of off-road vehicle performance, various semi empirical methods had been proposed by Wong and Alhimdani [3, 4]. To develop these methods successfully, the mechanical behavior of the terrain should be measured under loading conditions similar to those exerted by the vehicle methods for predicting tractive effort behavior and slip of off-road vehicles will be presented.

Still, methods for evaluating off-road vehicle performance are being continuously refined and improved [5,6]. When better mathematical models and terrain inputs are available, they could fit into the methodological framework presented here so that a more comprehensive picture [7,8,9] could be accomplished.

2. Previous Theoretical Related Work

One of the oldest and simplest criteria has been used by Bekker [10] since 1956. It postulates the material at a failure point where the shear stress at that instance in the medium satisfies the following general equation:

$$\tau_{max} = c + \sigma \tan \phi \quad \text{......} \quad (1)$$

where:

τ_{max}: is the shear strength of the material

c : is the apparent cohesion of the material

σ : is the normal stress on the sheared surface

ϕ : is the angle of internal shearing resistance of the material

To predict vehicle thrust, and slip, the relationship between the shear stress and shear deformation of the terrain is required. Thus the tractive effort of a track is produced by the shearing of the terrain.

In soft grounds, and desert soils, when cohesion is neglected (c = 0), the maximum tractive effort F_{max} that can be developed by the track is determined by the shear strength of the terrain (τ_{max}) and the contact area (A). In other words, following relation can be written as followes:

$$\mathbf{F_{max} = A \cdot \tau_{max}}$$

$$\mathbf{= A \cdot \sigma \cdot \tan\phi}$$

$$\therefore \mathbf{F_{max} = W \cdot \tan\phi} \quad \dots\dots (2)$$

where, W is the vertical load

The shear stress at a point located at a distance (x) from the front of the contact area and can be determined by:

$$\boldsymbol{\tau = \sigma \cdot \tan\phi \cdot (1 - e^{-ix/k})} \quad \dots\dots (3)$$

where:

x: is the distance from the front of the contact area
i: is the slip of the track
k: is the horizontal shear deformation modulus.

The total tractive effort developed by a track at a particular slip is represented by the area beneath the shear stress-displacement relationship and can be calculated as follows:

$$\mathbf{F = b\int_0^l \tau \cdot dx}$$

where, b is the track width

$$\therefore \mathbf{F = b\int_0^l \sigma \cdot \tan\phi \cdot (1 - e^{-ix/k})dx} \quad \dots\dots (4)$$

The above equation indicates that the tractive effort of a track depends among other factors on the normal pressure distribution over the contact area.

3. Utilizing simulation technique on current work

As it has been previously mentioned, five types of normal pressure distribution have been dealt with theoretically. Applying integration procedure of "MATLAB" in which the required integral is found for each type. This will be shown as follows:

3.1 Case 1: Uniform Normal Pressure Distribution

This is the simplest type of normal pressure distribution under the track, where the normal pressure is independent of (x) as shown in **Fig.(1)**.

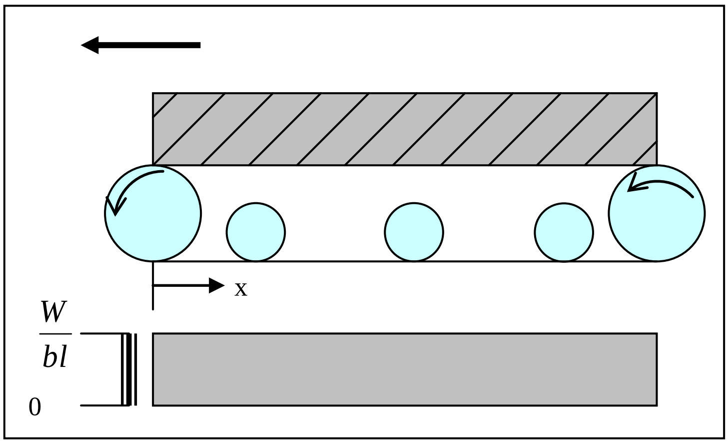

Figure (1) Case1: Uniform normal pressure distribution

$$\therefore \sigma = \frac{W}{b \cdot l}$$

The total tractive effort of a track is determined by equation (5)

$$\therefore F = b\int_0^l \cdot \frac{W}{b \cdot l} \cdot \tan\phi \cdot (1 - e^{-ix/k})dx \quad \text{.. (5)}$$

Simplifying this integral , the thrust ratio could be written

$$\frac{F}{F_{max}} = \left[1 - \frac{(1 - e^{-\beta})}{\beta}\right] \quad \text{.. (6)}$$

where:

F_{max} : is the maximum tractive effort and equal to $W \cdot \tan\phi$

β : is dimensionless factor which is equal to $i \cdot l / k$

3.2 Case 2: Normal Pressure Increasing Linearly from Front to Rear

For this case the normal pressure described by the following relation $\sigma = 2\left(\frac{W}{bl}\right)\left(\frac{x}{l}\right)$, as shown in **Fig.(2)**.

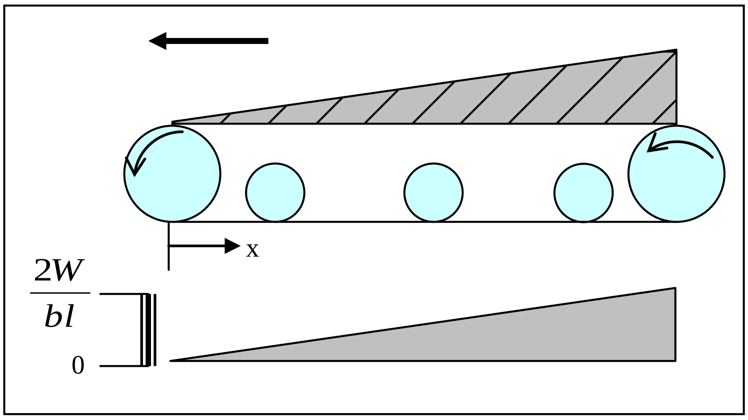

Figure (2) Case 2: Normal pressure increasing linearly from front of vehicle

In a similar way as in case (a), the tractive effort of a track is given by:

$$F = b\int_0^l \cdot \frac{2W}{bl^2} \tan\phi \cdot x\left(1 - e^{\frac{-ix}{k}}\right)dx$$

Performing the integral and simplifying the thrust ratio could be written as:

$$\frac{F}{F_{max}} = \left[1 - \frac{2}{\beta^2}\left(1 - e^{-\beta} - \beta \cdot e^{-\beta}\right)\right] \quad \text{...} \quad (7)$$

3.3 Case 3: Normal Pressure Decreasing Linearly from Rear to Front

In this case the normal pressure can be expressed as follows:

$\sigma = 2\left(\frac{W}{bl}\right)\left(\frac{l - x}{l}\right)$, as shown in **Fig.(3)**.

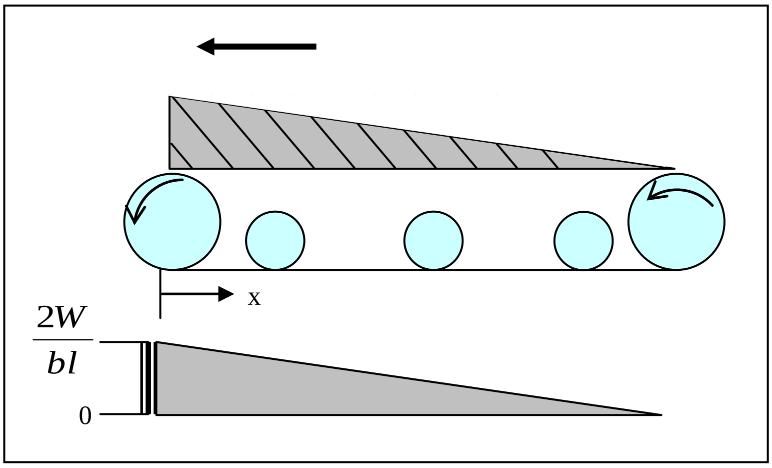

Figure (3) Case 3: Normal pressure decreasing linearly from front of vehicle

The tractive effort of a track is given by:

$$F = b\int_0^l \frac{2W}{bl^2}\tan\phi\cdot(l-x)\left(1-e^{\frac{-ix}{k}}\right)dx$$, after simplification the thrust ratio could be written as:

$$\frac{F}{F_{max}} = \left[2\left(1-\frac{(1-e^{-\beta})}{\beta}\right)-\left(1-\frac{2}{\beta^2}\left(1-e^{-\beta}-\beta\cdot e^{-\beta}\right)\right)\right] \quad \text{.............................. (8)}$$

3.4 Case 4: Sinusoidal Pressure Distribution Periodically as the Road Wheels

The normal pressure can be described by:

$$\sigma = \frac{W}{bl}\left(1+\cos\frac{2\pi\cdot n\cdot x}{l}\right)$$, as shown in **Fig.(4)**.

where, n is the number of periods which equal to the number of the road wheels.

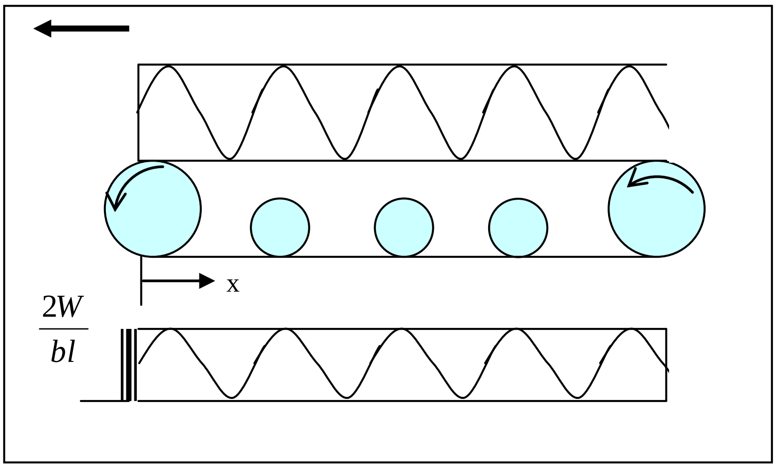

Figure (4) Case 4: Sinusoidal normal pressure distribution

Hence the tractive effort is given by:

$$F = b\int\cdot\frac{W}{bl}\cdot\tan\phi\cdot\left(1+\cos\frac{2\pi\cdot n\cdot x}{l}\right)\left(1-e^{\frac{-ix}{k}}\right)dx$$

Simplifying the above integration the thrust ratio could be written as:

$$\frac{F}{F_{max}} = \left[1+\frac{e^{-\beta}-1}{\beta}+\frac{e^{-\beta}-1}{\beta\left(1+\left(\frac{4n^2\pi^2}{\beta^2}\right)\right)}\right] \quad \text{.. (9)}$$

3.5 Case 5: Sinousoidal Pressure Distribution with Maximum Pressure at the Center and Zero Pressure at the Front and Rear Ends

In this case the normal pressure can be expressed as:

$\sigma = \frac{W}{bl} \cdot \frac{\pi}{2} \cdot \sin\frac{\pi x}{l}$, as shown in **Fig.(5)**.

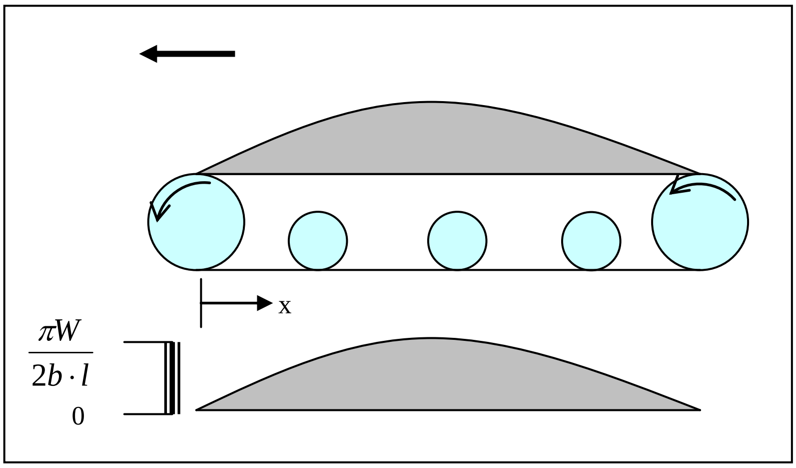

Figure (5) Case 5: Sinusoidal normal pressure distribution with maximum pressure at the center and zero pressure at the front and rear ends

The tractive effort is given by:

$$F = b\int_0^l \cdot \frac{\pi W}{2bl} \cdot \tan\phi \cdot \sin\frac{\pi x}{l} \cdot \left(1 - e^{\frac{-ix}{k}}\right) dx$$

Simplifying this, the thrust ratio could be written as:

$$\frac{F}{F_{max}} = \left[1 - \frac{1 + e^{-\beta}}{2\left(1 + \frac{\beta^2}{\pi^2}\right)}\right] \quad \text{.......... (10)}$$

4. Results and Conclusion

As it is shown in **Fig.(6)**, with the aid of computer and by using "MATLAB"; the equations which relate the tractive effort ratio with the slip are plotted. The abscissa represents the slip while the ordinate represents a dimensionless value of tractive effort as function of maximum tractive effort on a soft ground and desert. These represent equations 6, 7, 8, 9 and 10. The figure shows that the best tractive effort ratio with minimum possible slip is for the second case when normal pressure increasing linearly from front to rear end. In other words most of the weight is in the rear part of the tracked vehicle. A similar conclusion has been achieved by J. Pyttka [11] where soil stresses and deformation state under tracked vehicle loading has been accomplished. Also a reasonable good result in fifth case when the pressure distribution is sinusoidal and this curve is coincides on the second case curve at fourty percent of the slip, while the lowest tractive effort is obtained in the case when the pressure decreasing linearly, which gives in comparison with the other four studied cases minimum tractive effort ratio with the slip. **Figures (7)** and **(8)**, show the tractive effort for specified desirable slip ratio which is normally from 15% to 20% in agrarian vehicles. Also it can be shown that the recovery percentage reaches 16% at the ratio of 10% slip between the best condition (Case 2) and the worst condition (Case 3). In addition, this recovery has still a reasonable value of 11.55% at 15% slip and 9.42% for 20% slip. In other words, it is not advisable to use tracked vehicle where most of the weight is in the front of the vehicle.

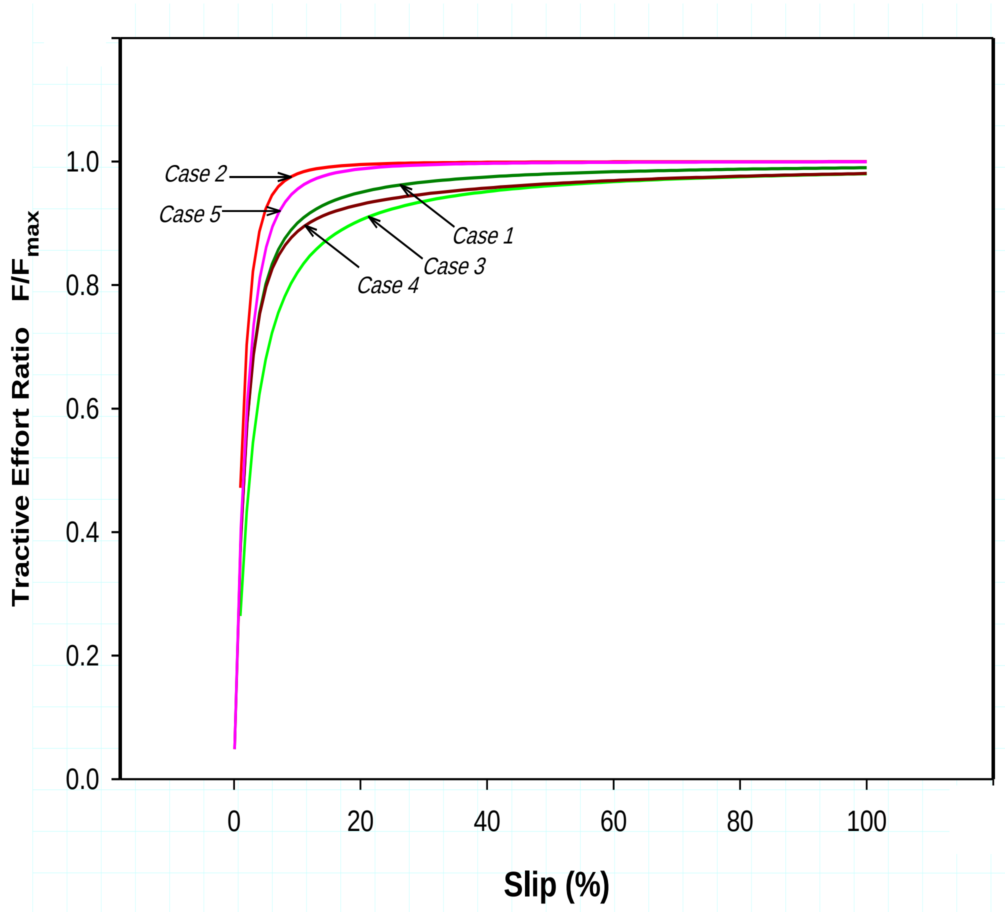

Figure (6) Tractive effort ratio against slip

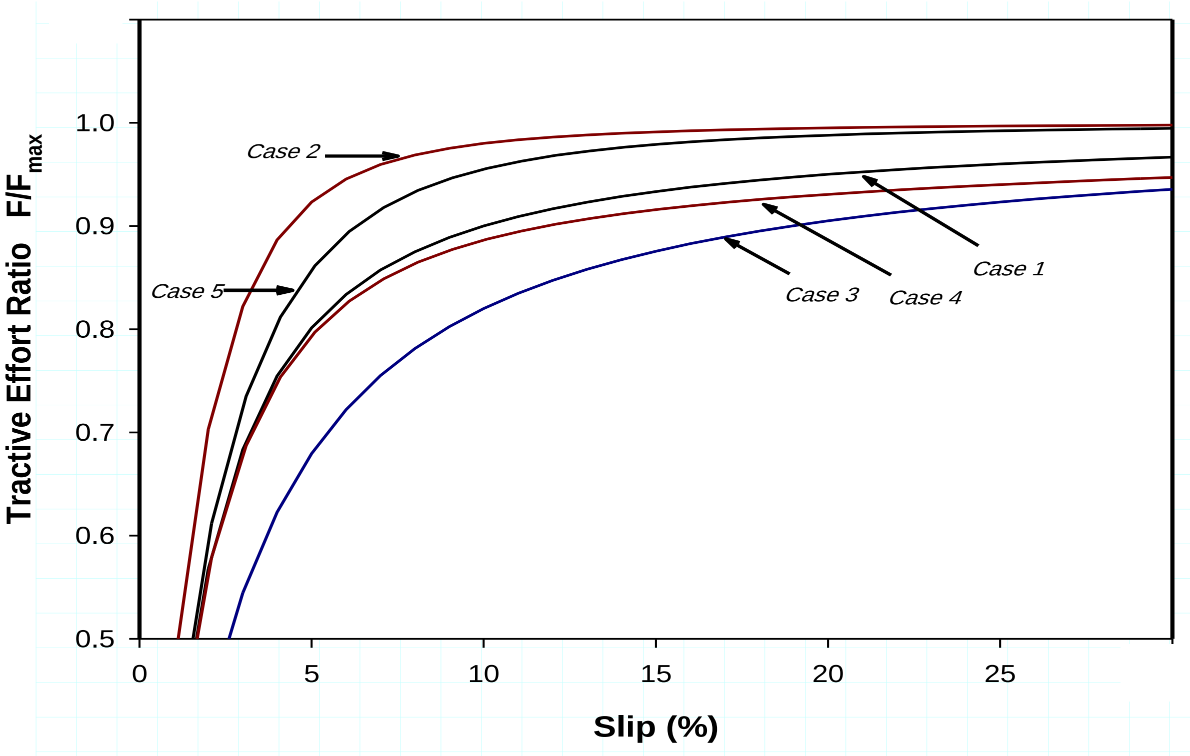

Figure (7) Tractive effort ratio against slip (zoomed sector)

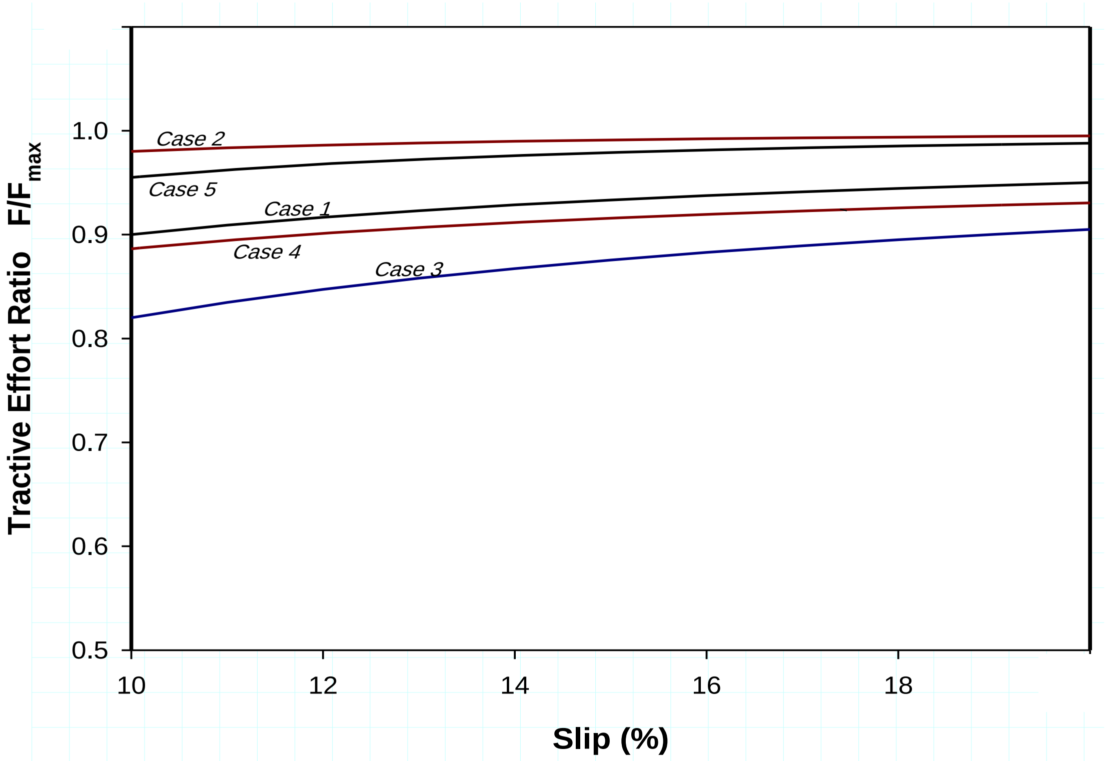

Figure (8) Tractive effort ratio against slip for the normal slip rande

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List of Symbols

A: Contact area
b: Track width
c: Cohesion of material (or soil)
F: Tractive effort
F_{max}: Maximum tractive effort
i: Slip of track
k: Horizontal shear deformation
l: Length of track
n: Number of road wheels
W: Vertical load
x: Distance from front of the vehicle
dx: Incremental distance
β: Dimensionless factor
σ: Normal stress
ϕ: Angle of internal shearing resistance of material
t: Shear stress