Journal of Engineering and Development, Vol. ١٧, No.١, Mar. ٢٠١٣, ISSN ١٨١٣- ٧٨٢٢

THE EFFECT OF WEIGHT DISTRIBUTION ON THE REQUIRED STEERING TRACK-FORCES IN TRACKED VEHICLES

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Abstract :

During the last eighty years, there have been many improvements in the design of tracked vehicles. Great achievements have been established in both, the required engine-transmission systems and also in the shape of tracked vehicles. However, the effect of weight distribution on the required steering track-forces has not been fully developed completely. This work is mainly concerned with analysing the effect of weight distribution of a tracked vehicle on the required steering track forces. Previous works had dealt only with uniform normal pressure distribution. There has been hardly any theoretical analysis regarding the effect of different weights distribution on the required steering tracked forces. As a result, a new analysis has been established relaying on previous theoretical work for uniform normal pressure. It has been concluded that the required steering track forces when Centre of Gravity is near the front of the tracked vehicle are less than that when tracked vehicles carrying uniformly distributed weight.

تأثير توزيع الثقل على القوى اللازمة لدوران المجنزرات

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الخلاصة

خلال الثمانين سنة الماضية (١٩٣٠-٢٠١٠) أجريت بحوث عدة على تطوير شكل المجنزرة ومحركها وتأثيرهما على كفاءة الأداء.لكن شكل المجنزرة وبشكل خاص كيفية توزيع الثقل ومدى تأثيره على القوة اللازمة للدوران لا تزال غير واضحة تماما ولم يتم دراسته و تطويره بشكل كامل, ونجد بأن معظم البحوث السابقة قد أجريت فقط في حالة التوزيع المنتظم للوزن ونادرا ما يوجد بحوث لبقية الحالات (التوزيع غير المنتظم) ومدى تأثيره على القوى اللازمة للدوران. في هذا الجزء من البحث تم الاعتماد على البحوث السابقة للتوزيع المنتظم للوزن لاشتقاق التحليل النظري لبقية الحالات لتوزيع الوزن.لقد تم الاستنتاج على ان اقل قيمة للقوة اللازمة لدوران المنجنزرة يتم الحصول عليها عندما يكون وزن المجنزرة قريب من مقدمة المجنزرة ويتضح مما سبق انه كلما كان وزن المجنزرة قريب من المقدمة كان هذا أحسن للدوران.

NOTATIONS-:

Variable	Meaning	Unit
B	Width of the tracked vehicle	m
	Inside track force	N
	Outside track force	N
G	Acceleration due to gravity	m/
H	height of C.G above the ground	m
L	Ground contact track length	m
R	Turning radius of the tracked vehicle	m
	Motion resistance of inside track	N
	Motion resistance of outside track	N
S	Speed of tracked vehicle	m/
W	weight of tracked vehicle	N
Ө	Angle of turning	degree
	Coefficient of lateral skidding friction	dimensionless
	Coefficient of longitudinal friction	dimensionless
	)	dimensionless

١-Background

For more than a century, tracked vehicles have been in use in many applications such as military, construction, and agricultural. Many studies have been developed in tracked vehicles and many research papers have been published. Bekker [١٩٥٦] may be regarded to be the first person who made an extensive ground work in the field of terramechanics. He proposed and established the fundamental concepts of tracked vehicle mechanics. This has been widely accepted and used later by researchers in this field. His works were later revised and reorganized by many, especially in drawbar analysis by Wong [١٩٧٨] and also, by Kitano[١٩٧٦] and Alhimdani [١٩٨٢] in steering analysis. In the past, the choice of conventional tractive elements used for off-road vehicles to generate tractive effort was mainly restricted to either pneumatic tyres or steel tracks. But, nowadays, it is commonly recognized that tracked vehicles are better draught tractors. This is because of its capability of producing a high drawbar pull at a lower slip value .Even under difficult conditions such as on a very soft surfaces, a tracked vehicle has a high tractive efficiency. The large ground contact areas of the tracks result in low ground pressure and good stability on steep slopes. However, steel tracks have adverse characteristics when compared to pneumatic tyres from the point of view of steerability, manoeuvrability, noise, driver fatigue, maintenance and limited speeds. In addition, travelling on public roads is restricted in most areas due to road surface damage from penetration by the steel track grousers.

For many years, there has been an interest in developing rubber tracks to be used on tractors. This was done to combine the good tractive performance and low ground pressure of the steel tracks with the non-abrasive features, higher speeds, and asphalt road-going capability of the pneumatic tyres. In recent years, the availability of rubber compounds and methods of steel reinforcement have enabled the manufacturers to construct rubber tracks of adequate strength and durability for use on agricultural tractors and even earth moving machines. These tracks are cost effective and lighter than the conventional steel tracks. When summarized and compared to steel tracks, rubber tracks offer additional advantages.

The need for single tracked vehicles of all types is owing to their increased level of performance over wheeled vehicles in off-road operations. This is because of their importance in terrains characterized by muds, snows and similarly weak surface ground. However, the real tractive effort for low speed drawbar pull, and also the steering of these vehicles is still a considerable problem [١]. Over the past six decades, many improvements have been achieved in the design of tracked vehicles [٢, ٣] .There have been considerable efforts devoted to the study of traction mechanics and mobility in off-road applications for single tracked vehicles.

These vehicles have been used usually on soft ground at low speeds, and also on hard terrain at high speed.

Recently, the operational running speed of vehicles has been increased due to their increase in engine power [٤, ٥]. It is not only essential to analyze mobility , but as well the stability of these vehicles .Track forces have been obtained from the steady state and dynamic analysis of moderate and high speeds of single tracked vehicles by several investigations for both drawbar pull and uniform turning motion. And as a result, the drawbar pull, the steerability, and mobility of these vehicles have been greatly improved [٦،٧].

Carrying Weight Previous Theoretical Work on Steering of Tracked Vehicle Uniform ٢-

With regard to turning at low speed, the forces are shown in Fig .(١).The centrifugal force has been neglected because the vehicle is turning at low speed. It is worth mentioning that, all lines for centroid ,C.G and turning are all coincide with each other. Summing-up the horizontal forces (٠ = ∑) and moments ,(٠= ∑) the following equations have been deduced and well established- :[٨،١٠]

=+ ……………………………………………………(١)

= ……………………………………………………(٢)

Furthermore, and when the vehicle is turning at high speed around centre point o, the centrifugal force should be taken into account. It can be seen that, the turning line will be shifted a head from centroid and C.G line in Fig. (٢). The values of outside and inside thrusts have been already established which are [٩،١١]:-

= (+) + – + …………………..(٣)

= (-) + + - …………………..(٤)

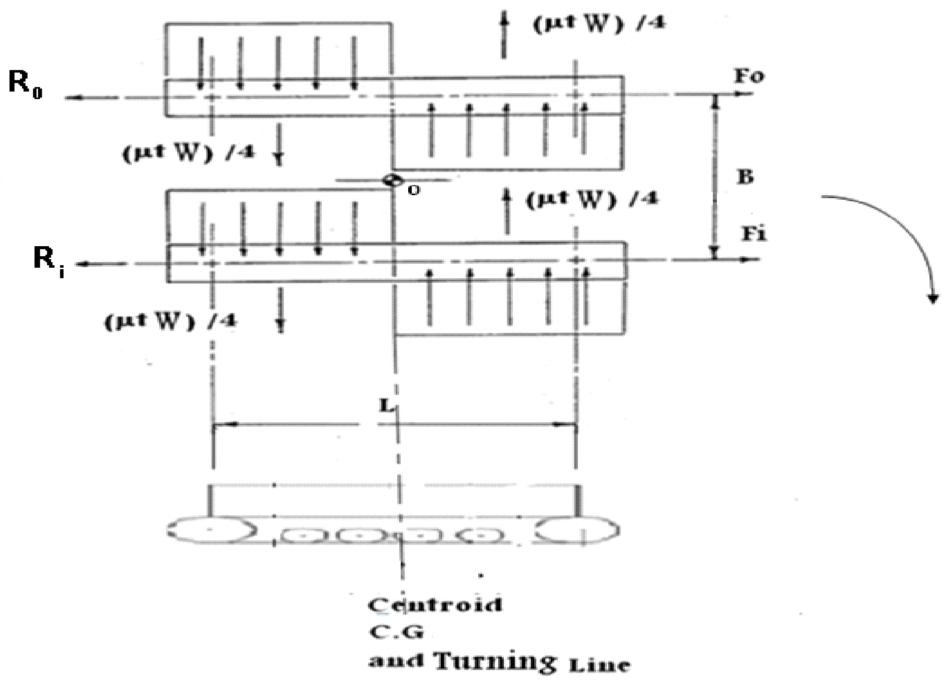

Fig. (١)Forces affecting turning for a single tracked vehicle at low speed [١١]

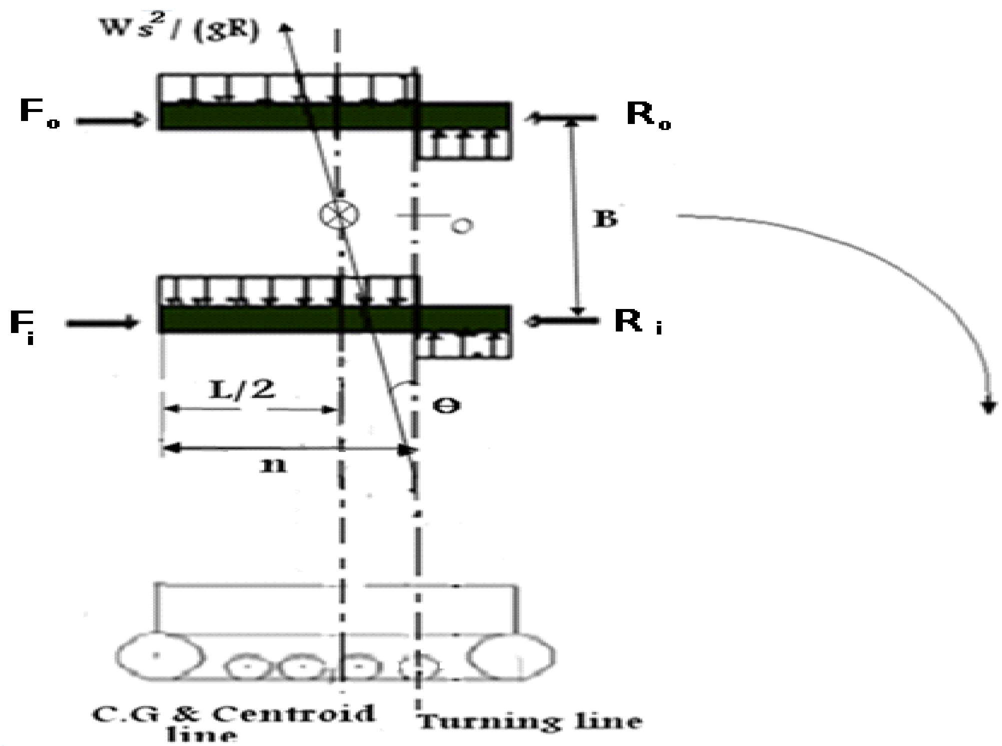

Fig.(٢)Forces affecting turning at a high speed showing the centrifugal force at uniform normal pressure [١١]

Equations(٣ and ٤) represent the required steering track forces when a tracked vehicle is turning at high speed and when uniform normal pressure has been assumed. Results using the above equations are well known and have been well established which are used for evenly distributed weight carried on the tracked vehicle. So, a similar analysis relying on this theoretical approach is used for "non-uniform" normal pressure.

٣. The Effect of Weight Distribution on the Required Steering Track-forces for Normal Pressure Increasing Linearly from Front to Rear (C .G is near the rear)

In this section and when C. G is near the rear, two types of analyses will be discussed. These are for turning at low speed and at high speed. Turning line (T.L) will not be the same line passing through C.G. This will be explained, as follows:-

٣،١ Low Speed Turning Analysis When C.G is Near the Rear:-

When turning at low speed, the effect of centrifugal force has been neglected. All related forces are shown in Fig (٣).

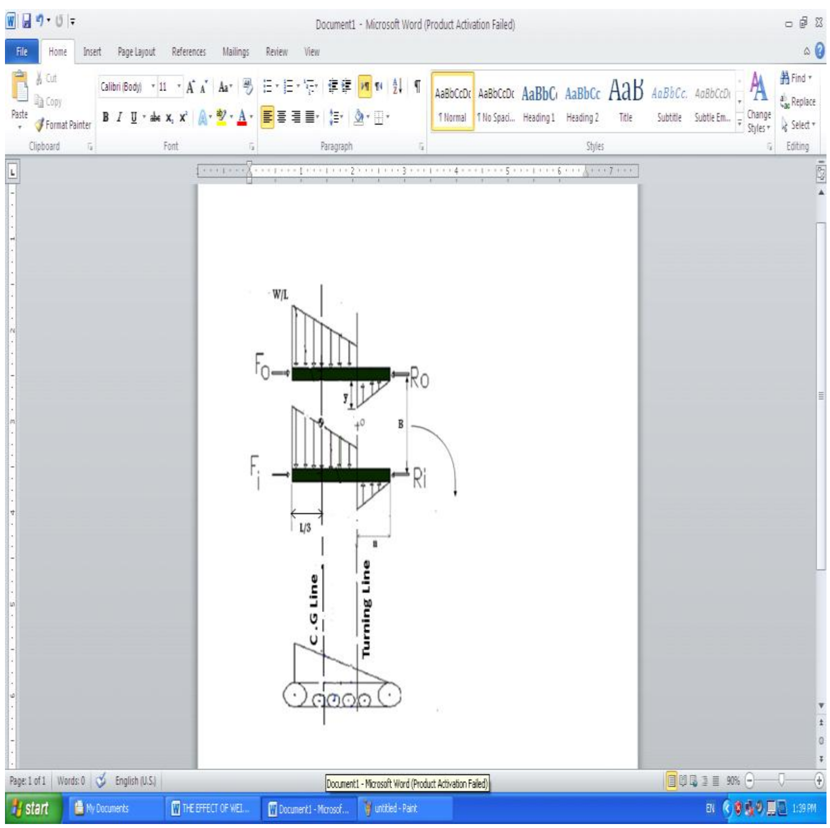

Fig. (٣)Required Low-Speed Turning Forces when C.G is near the rear.

It is obvious that, the C. G line is equal to the third of track length( ) from the rear . It can be seen from the already mentioned figure and by similarity of triangle:

= / L

=

The position of the turning line is unknown, but it can be easily calculated by summation of vertical forces, then :-

n = ٠,٧٠٧ L

This result is quiet reasonable , since as a result of shifting the C.G to the rear , the turning line will be behind the C.G line or near the vehicle rear, as shown in Fig.(٤). The following two equations can be concluded[١٢] as follows:--

= **……………………………………………….(٥)**

= **……………………………………………….(٦)**

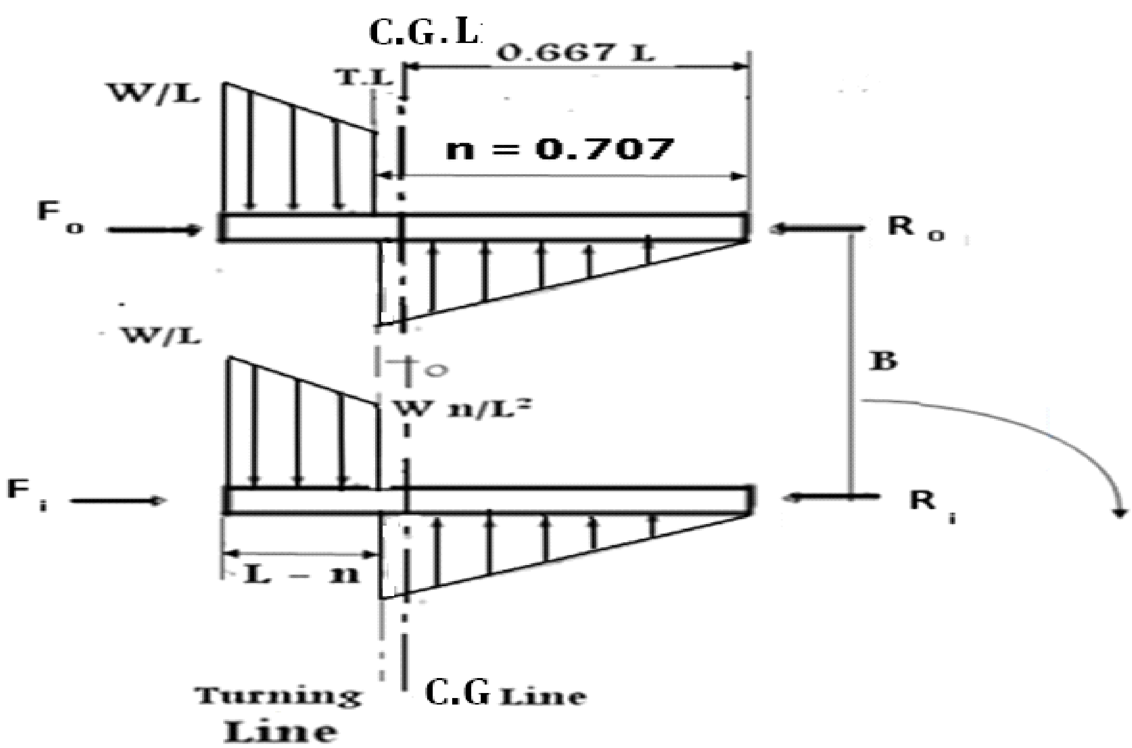

Fig. (٤)The effect of having C.G near the rear which leads to shift turning line to a new position when the tracked vehicle is turning at low speed

Equations(٥) and(٦) represent the required steering track-forces of a tracked vehicle turning at low speed when C .G is near the rear, there is an improvement in Outside and inside track force. This is because the value of . This is a very interesting result since in the previous analysis, the value of modulus[is always greater than the value of modulus[. The object is to bring both values of and near the zero thrust line. In this new result, there will be a decrease in the both modulus values. This will be shown later figures in the theoretical results.

٣,٢ High- speed Turning Analysis When C.G Near the Rear:-

When the tracked vehicle is turning around turning point at medium and high speed, the centrifugal force effects should be taken. As in the previous results, all forces are shown in Fig.(٥). The turning line will again be shifted but to the front of C. G. This is due to the effect of centrifugal force.

Since the turning radius(R) is usually large compared with the small part of contact length of track (L),() would be small &cos()=١

n = ٠,٧

the values of outside and inside thrusts can be concluded as follows[١٢]:-

=(++()³+(١)².(+ (١))(…………………..(٧)

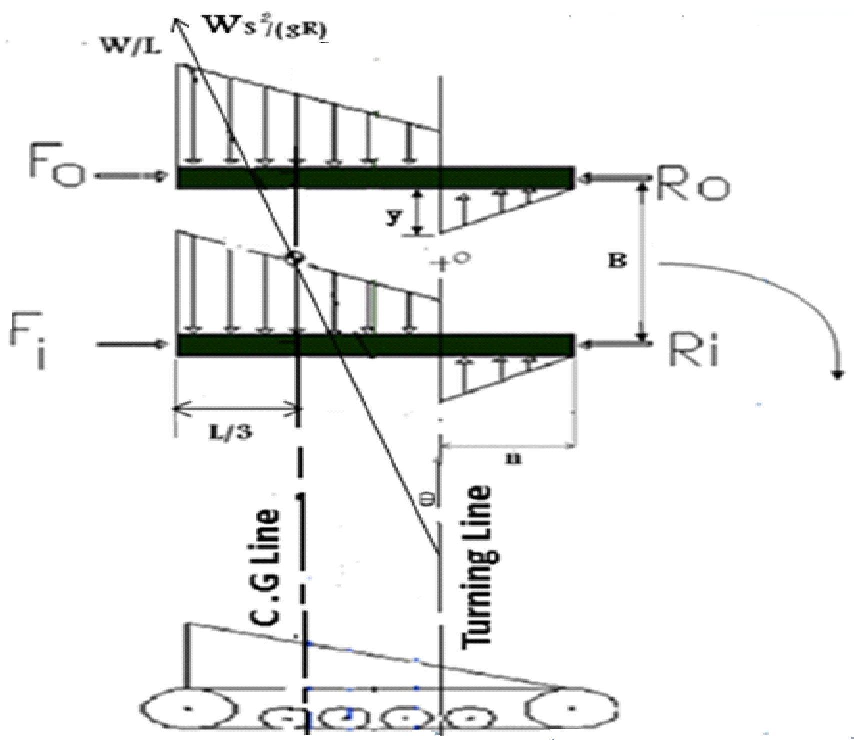

Fig. (٥)Required High-Speed Turning Forces when C.G is near the rear.

=(()³(١)²((١))+(

٤. The Effect of Weight Distribution on the Required Steering Force when Normal Pressure Decreases Linearly from Front to Rear(C.G is near the front)

In this section and when C. G is near the front, as mentioned before two types of analysis will be discussed. These are for turning at low speed and at high speed. Turning line (T.L) again will not be the same line passing through C.G. This will be explained, as follows:-

٤,١.Low Speed Turning Analysis When C.G is Near the Front:-

When turning at low speed, centrifugal force effect has been neglected. All related forces are shown in Fig (٦).

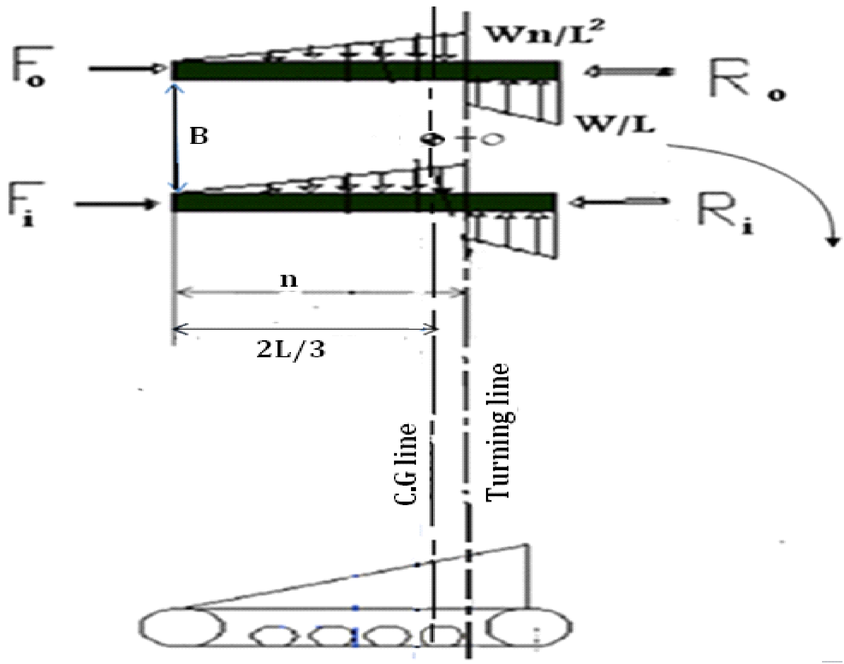

Fig.(٦) Required Low-Speed Turning Forces when C.G is near the front

It is obvious that, the C. G line is equal to the third of track length ( ) from the front.The position of the turning line is unknown, but it can be easily calculated by summation of vertical forces, then:-

n = ٠,٧٠٧ L

the following two equations can be concluded:-

= ……………………………………………(٩)

= ……………………………………………(١٠)

The above two equations mean that in this case (C.G is near the front),there will be an improvement for both, inside and outside steering force. This is because the value of . This is a very interesting result since in the previous analysis, the value of modulus [is always greater than the value of modulus [. The object is to bring both values of and near the zero thrust line. In this new result, there will be a decrease in the both modulus values. This will be shown in the theoretical results.

٤،٢.High- speed Turning Analysis When C.G is Near the Front:-

When turning at high speed, the centrifugal force effects should be taken into account. As in the previous results, all forces are shown in Fig.(٧). The tracked vehicle is turning around point o. The turning line will again be shifted but to the front of C. G. This is because of the effect of centrifugal force.

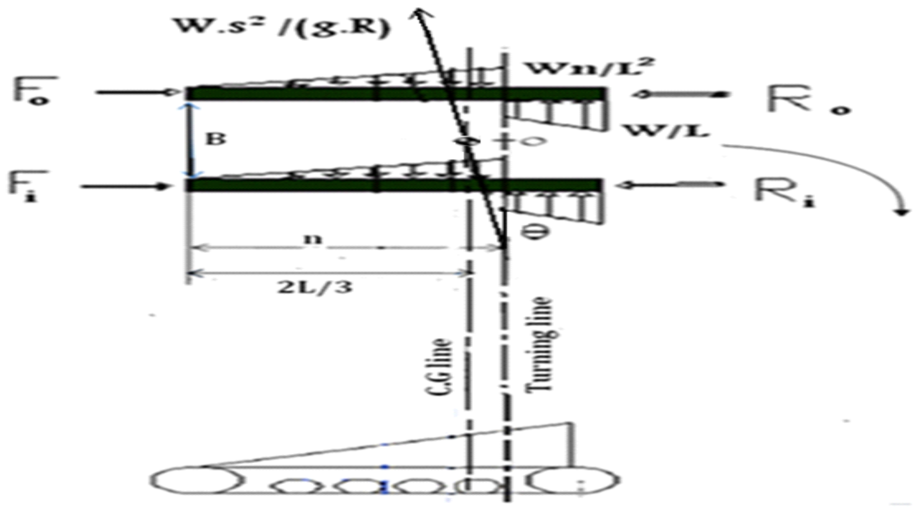

Fig. (٧) Required High-Speed Turning Forces when C.G is near the front

n =

The values of outside and inside thrusts can be deduced as follws:-.

=(++()³+(١)² + (١))(……………….(١١)

=(()³(+ (١))(………………(١٢)

٥.Summarized Comparison among Three Cases Showing Position for C.G Line and Turning Line . It is worthwhile mentioning that there is a difference in the analysis between steering at low speed and steering at high speed. This is summarized, which is shown in Fig.(٨). Three cases have been taken into account. These are, uniform pressure distribution (previous analysis [٣١]), C.G is near the rear and C.G is near the front. Inotherwords, six cases have been considered where the position of the turning line changes in each case of the six conditions.Only the steering analysis under uniform pressure distribution is well known and is already published. This is shown in the Figs.(٨-a) and(٨-b). At low speed, both C.G line and turning line coincide with each other. While at high speed, the turning line is between the C.G line and the front of the vehicle.With regard to case (٢) of which C.G is near the rear, the turning line will be between the C.G line and the rear of the vehicle at low speed. However, at high speed, the turning line will be between the C.G line and the front of the vehicle. This fact has never been published and is shown in Figs. (٨-c) and(٨-d). Finally, in case (٣) of which C.G is near the front, the turning line will be between the C.G line and the front of the vehicle for both a low and high speed. Again this is regarded as a new fact , as shown in Figs. (٨-e)and (٨-f).

٦.Theoretical Results for The Required Steering Track Forces of a Tracked Vehicle:-

With regard to steering of tracked vehicle at low speed, two approaches have been used. The first is a simple approach by ignoring completely ly the centrifugal force. The values of the required steering outside and inside track forces in dimensionless quantity

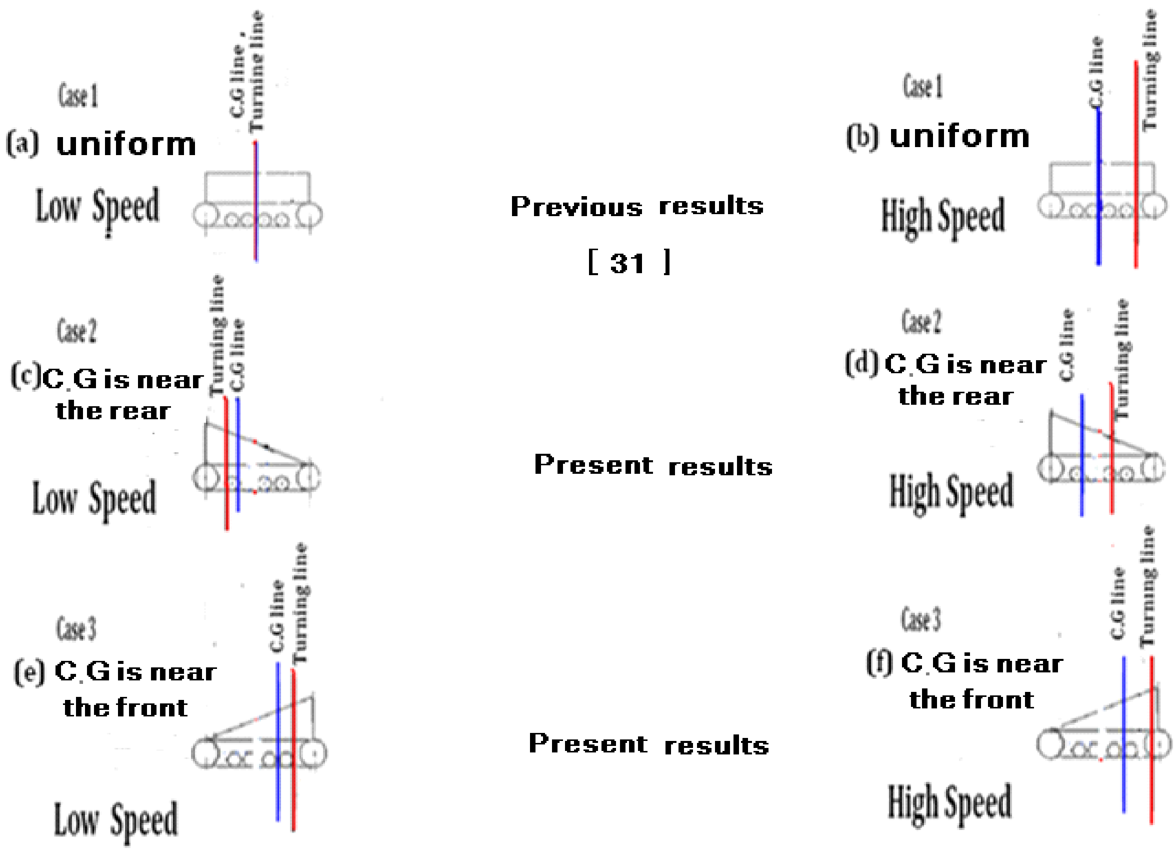

Fig. 3-16 Comparison among three cases for finding both position for C.G line and turning line when steering a tracked vehicle at low speed and high speed.

Fig. ٨ Comparison among three cases for finding both position for C.G line and turning line when steering a tracked vehicle at low speed and high speed

)$\frac{F_o}{\mu_t W}\frac{F_o}{\mu_t W}$ (and) $\frac{F_i}{\mu_t W}\frac{F_i}{\mu_t W}$ (have been calculated .These have been computed using the following equations at low speed from the previous section-:

- Equations(١)and(٢) for normal pressure distribution.

- Equations(٥) and (٦) when C.G is near the rear (normal pressure increasing linearly from front to rear).

(iii) Equations (٩) and (١٠) when C.G near the front (normal pressure decreasing linearly from front to rear).

The result is shown in Fig.(٩) which is independent of radius of turn. This is because the centrifugal force (which is a function of radius of turn) has been ignored. It is interesting to observe that there is an improvement in the steering procedures. When C.G is shifted either to the front or to the rear, less required steering forces are needed than that for uniform pressure distribution. This is because of the decrease in the resisting turning moment when non-uniform distribution pressure is used. In other words, when C.G is near the rear or the front, resisting moment is reduced and thus less required steering forces are needed.

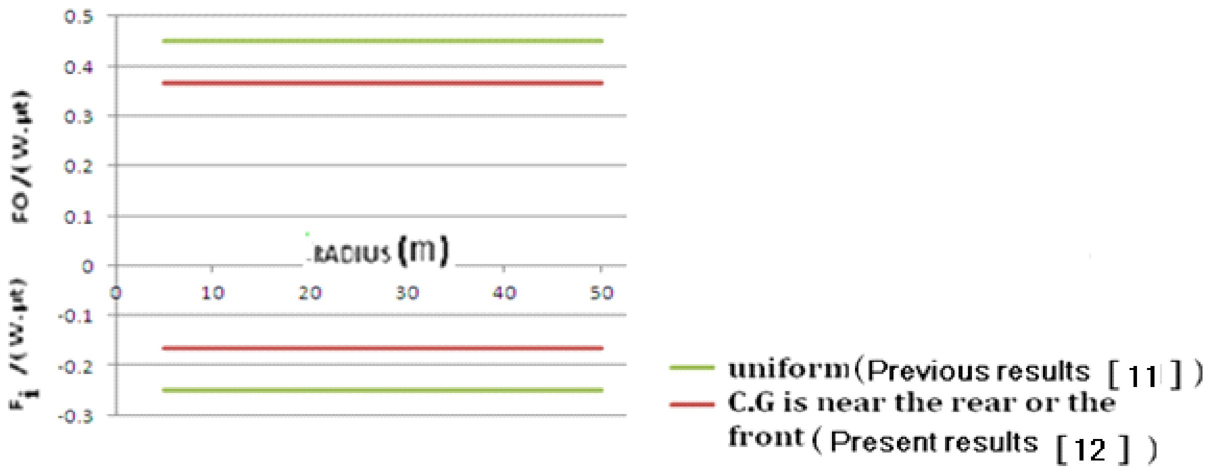

Fig.(٩) Comparison between required inside and outside steering track force against turning radius for three cases of pressure distribution, using simple approach.

The second approach is by using the equations used for high speed in which the centrifugal force has been taken into account and different values of turning radius are used. This is accomplished using the following equation:-

- Equations (٣) and (٤) for normal pressure distribution.
- Equations (٧) and (٨) when C.G near the rear (normal pressure increasing linearly from front to rear).
- Equations (١١) and (١٢) when C.G near the front (normal pressure decreases linearly from front to rear).

Two values of low turning speed are used but both give nearly similar results. The values of speed are ٥ km/h and ١٠ km/h, and the obtained results are, as follows:-

(i) For Uniform pressure, the results are shown in Fig.(١٠)

(ii) C.G near the rear, the results are shown in Fig.(١١)
(iii) C.G near the front, the results are shown in Fig.(١٢)

It can be seen that, the centrifugal force effect is hardly noticeable except when turning radius R is small because the centrifugal force becomes large. Therefore, the value of outside and inside track force at low speed will be nearly constant when R is large. When both C.G are near the rear and the front they have nearly similar results because the speed is low. It can noticed that there is a similarity between Figs (١٠), (١١), and (١٢).

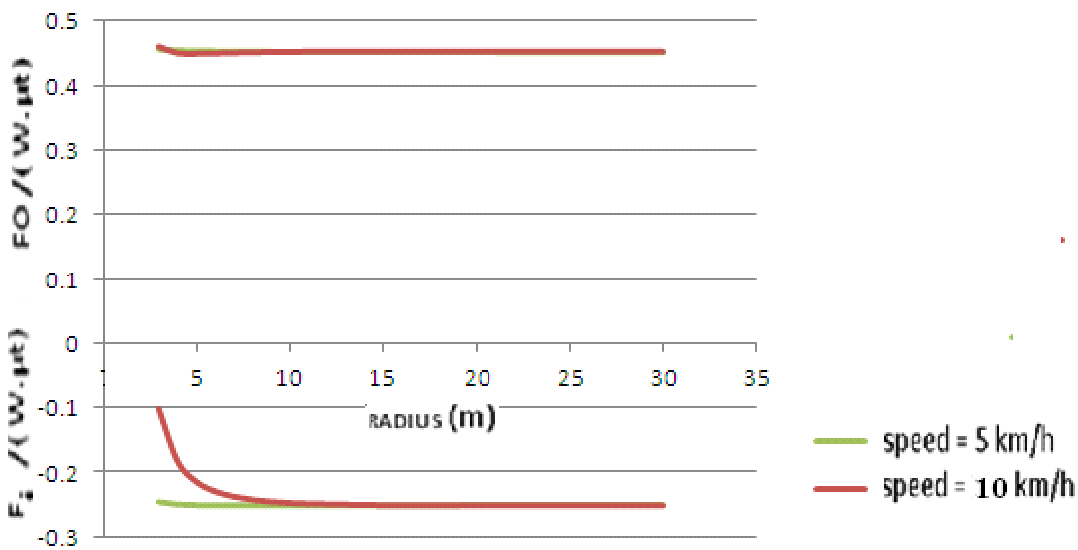

Fig.(١٠) Required inside and outside steering track force against turning radius for uniform pressure distribution at low speed turning.

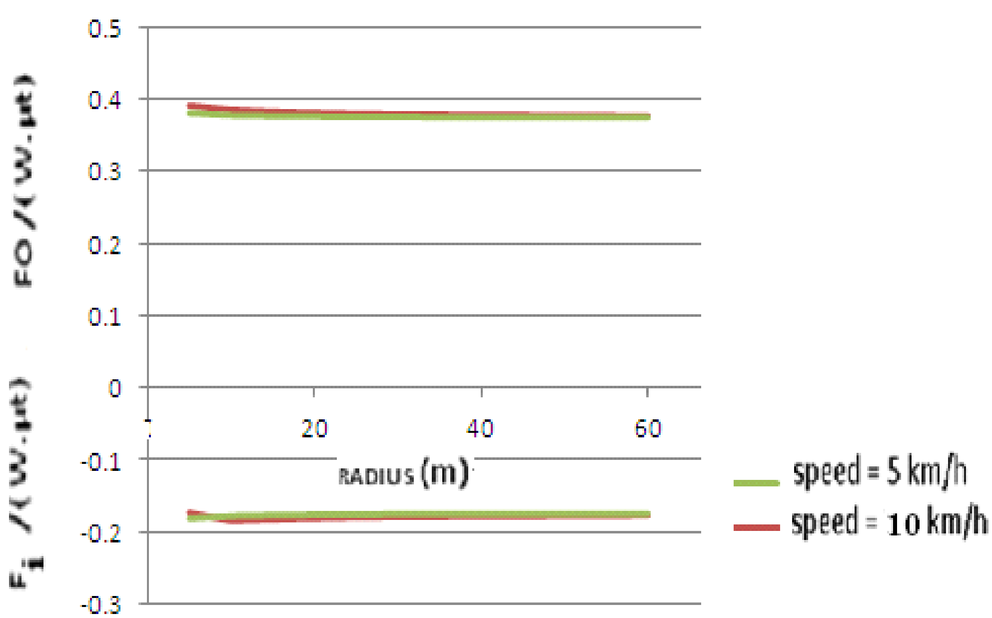

Fig.(١١) Required inside and outside steering track force against turning radius for normal pressure increasing from front to rear (C.G is near the rear) at low speed turning.

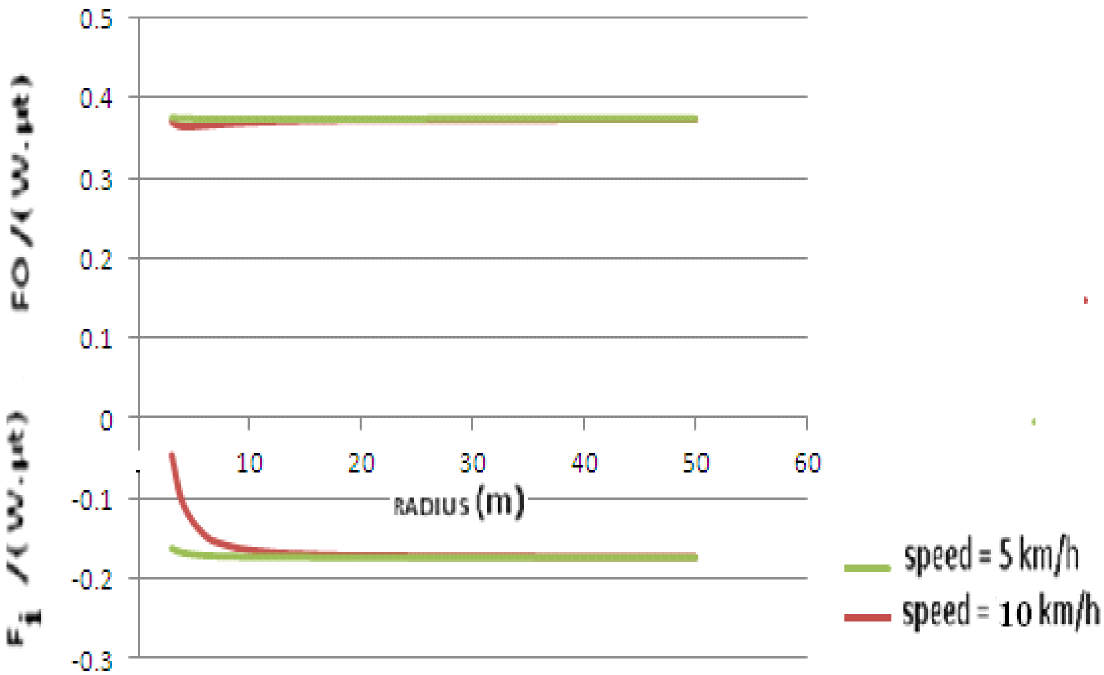

Fig (١٢). Required inside and outside steering track force against turning radius for normal pressure decreasing from front to rear (C.G is near the front) at low speed turning.

A comparison is then made between the previous results which are made for uniform pressure and those when C.G is shifted either to the front or to the rear. This is shown in Fig. (١٣&١٤). It can be seen that, the values of outside and inside track force (Fo, Fi) have been decreased both when C.G is shifted to the rear or to the front. In other words, there is improvement when C.G is shifted towards the front or rear. The required inside and outside track forces will be less than those required for uniform pressure distribution. This is regarded remarkably as interesting result. The improvement is noticeable which might amount to nearly ١٧ %. This improvement is attributed to the decrease in turning moment resistance when C.G is near the rear or the front.It is worthwhile mentioning that all of the mentioned theoretical results had been verified by Haithem Faleh[١٢].This was accomplished in ٢٠١١ using an experimental model for a tracked vehicle at Al-Mustansiriyah University.

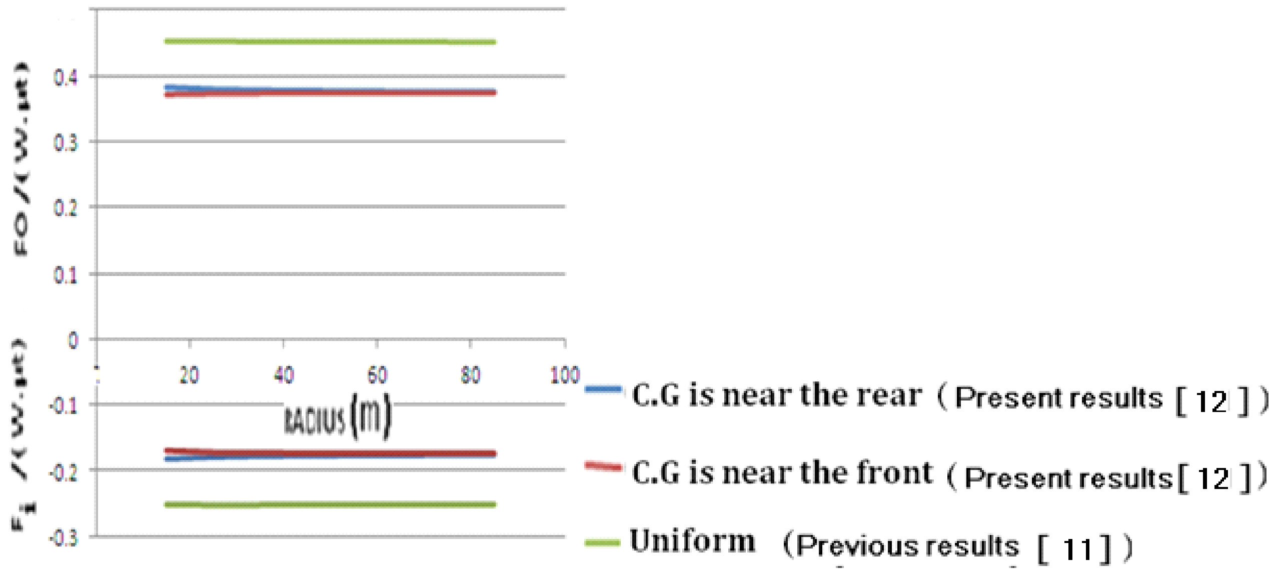

Fig ١٣.Comparison between Required inside and outside steering track force against turning radius for three cases of pressure distribution at speed = ١٠ km/h.

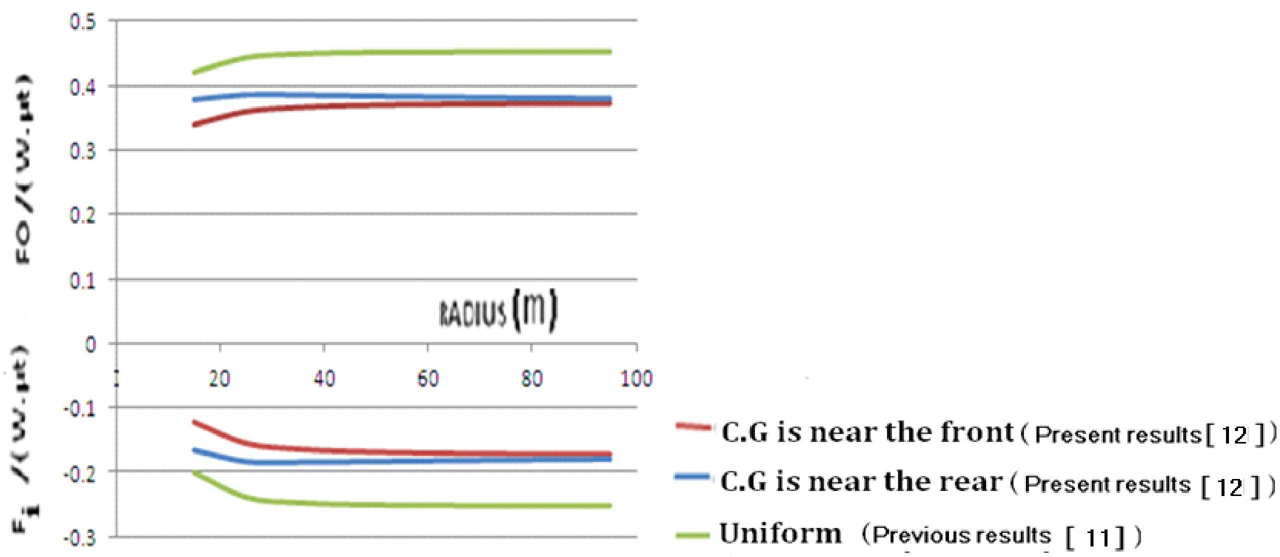

Fig (١٤)Comparison for required steering inside and outside track forces against turning radius for three cases at speed = ٢٠ km/h (high speed).

٧. *Conclusion* :-

With regards to steering analysis of tracked vehicle , there have been remarkable concluding points which will be explained and summarized . Most of these points are nearly new and have not yet been published. Whether it is valuable or not ,
only time will tell in the future.The following remarks could be concluded :-

- When a steering a tracked vehicle at low speed, it has been concluded that the values of outside and inside track force (Fo, Fi) have been decreased when C.G is shifted to the rear or to the front. In other words, there is improvement when C.G is shifted towards the front or rear. The required inside and outside track forces will be less than those required for uniform pressure distribution. This may be considered as remarkably interesting result. The improvement is noticeable especially at large radius of turn when C.G is near the front which might account to nearly ١٧٪ improvement.

٢-When turning a tracked vehicle at high speed, the following points have been concluded:

i - In general, when steering of tracked vehicles is at any speed, the best case is when C.G is near the front and the worst case is the uniform pressure distribution.

ii- The change in weight does not affect the comparison between the three cases when the steering of the tracked vehicle, but the speed is the important factor.

iii- The required track forces will decrease when speed of turning is increased for the three cases of pressure distribution.

iv - When C.G is near the rear, there will be a limited value for the turning radius which will decrease with the increase in turning speed .For example, at speed nearly equals ٢٠ km/h, the turning radius must be more than ١١ m, and at speed nearly equals ٣٠ km/h, the turning radius must be more than ١٥ m. At speed nearly equals ٥٠ km/h, the turning radius must be more than ٤٠ m.

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