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Dynamic Analysis of Steering Articulated Tracked Vehicles

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Abstract

There has been an increase in the use of articulated tracked vehicles during the past two decades. This is because of the limitations imposed on steering single tracked vehicles.

In this work, which is regarded as the first part of dynamic analysis of steering articulated tracked vehicles, the effect of centrifugal acceleration has been taken into account, at low and also at high speed. The object is to compare steering analysis between single tracked vehicles and the wagon type of articulated tracked vehicles in the influence of centrifugal force.

الخلاصة

في خلال العشرين السنة الماضية كانت هناك زيادة ملحوظة في استخدام المجنزرات المقطورة، وذلك بسبب المشاكل والمعوقات التي تواجه المجنزرات (الاعتيادية) خلال الدوران.

في هذا البحث وهو الجزء للتحليل النظري الديناميكي للمجنزرات المقطورة، أُخِذ بنظر الاعتبار تأثير التعجيل المركزي عند الدوران في سرع بطيئة وكذلك عند السرع العالية. إن الغاية من البحث هو مقارنة تحليلية لعملية الاستدارة بين المجنزرات الاعتيادية والمجنزرات المقطورة، وخاصة تأثير القوة الطاردة المركزية على القدرة اللازمة للدوران.

1. Introduction

Nowadays, there are many applications of articulated tracked vehicles. They can be used as transporters for heavy equipment [1], or in the field of Agriculture [2]. It can be utilized also as desert transporters or carriers of passengers on snow and sand terrains. Also, it can be used as forest fire tracked vehicles [3]. In addition and most important, it can be used valuably in the applications of military vehicles for pulling tracked trailers and towing knocked out tanks from battlefields [4].

The maneuverability of articulated tracked vehicles can be excellent because it requires usually less power to execute a turn comparing with single tracked vehicle. Improved obstacle crossing and-uniform ground pressure are advantages in applying articulation to tracked vehicle [5,6]. Great Facility is achieved by articulation because it permits the track to conform to the shape of ground and thus more uniform pressure is obtained. Long, narrow vehicle encounters less obstacle and motion resistance over unprepared terrain than short, wide vehicle with the same tracked contact area. However, there was an impediment straightening up problem when steering articulated tracked vehicles. This problem occurs in the Wagon type of articulated tracked vehicles [7]. Alhimdani and Younis tried to solve this problem theoretically using one hydraulic piston [8]. However, it was found it is not practical and the problem has not been completed and has not been solved yet.

A new idea was suggested to overcome the steering impediment problem during straightening maneuver of articulated tracked vehicles. This was achieved by using high tension ropes between the towing tracked vehicle and tracked trailers [9]. Two loose ropes have been used during turning. However, one of the ropes will be tightened when the system starts to straighten up. In this work, the effect of centrifugal force has been taken into account and only in the turning position, while the straightening up position has not been studied. And as a result, the ropes have no influence on this analysis. The aim is to carry out a comparison of centrifugal force effect on steering between single tracked vehicle and articulated tracked vehicle.

2. Theory

Consider a single tracked vehicle which is turning steadily as shown in **Fig.(1)**. Previous analysis, which takes into account the centrifugal force effect, has been accomplished by Wong [10]. His work can be summarized by the two following dimensionless equations for calculating outside and inside track forces [11]:

$$\mathbf{R_{OT}} = \left(\frac{1}{2} + \frac{R_{hB}.S^2}{gR}\right)R_\mu + \frac{LS^4}{4\mu_t^2.g^2.R^3} + \frac{R_{LB}}{4}\left(1 - \frac{S^4}{g^2.R^2.\mu_t^2}\right) \text{..........................} \quad (1)$$

$$R_{IT} = \left(\frac{1}{2} - \frac{R_{hB}.S^2}{gR}\right)R_\mu + \frac{LS^4}{4\mu_t^2.g^2.R^3} - \frac{R_{LB}}{4}\left(1 - \frac{S^4}{g^2.R^2.\mu_t^2}\right) \text{………………… (2)}$$

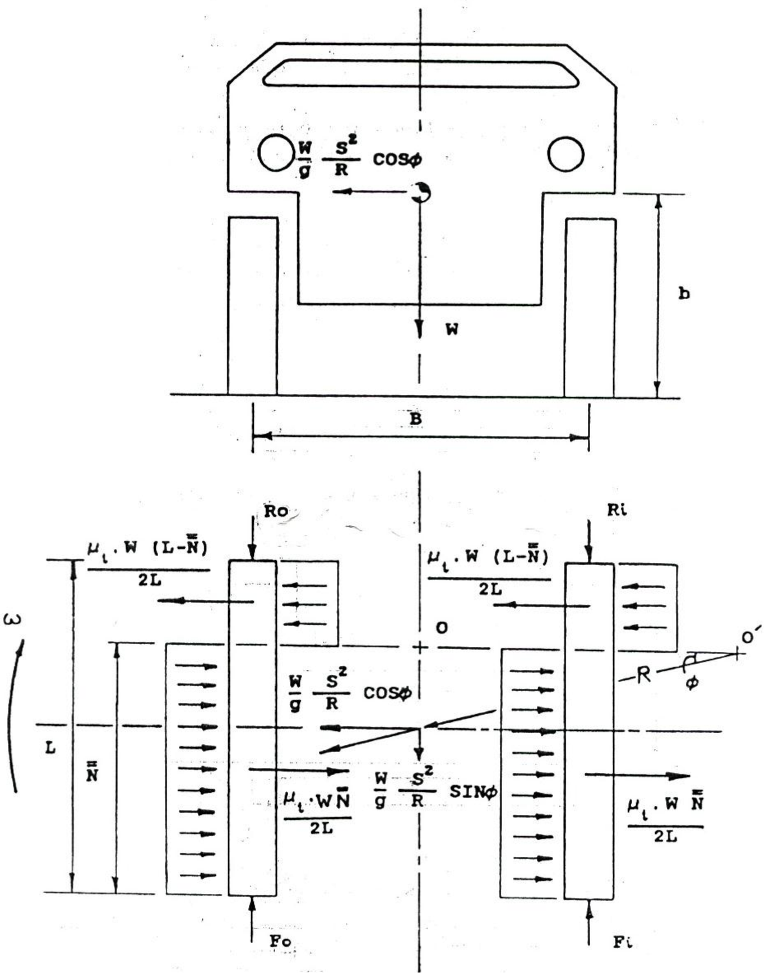

Figure (1) Forces acting on a single tracked vehicle during a turn at a moderate or higher speed [10]

Moreover, and with regard to the analysis of steering articulated tracked vehicles, a work has been achieved in 1995 by Yahya [9]. This is shown in **Figs.(2, 3 and 4)**, where the effect of centrifugal force has been taken into account. Yahya's work can be summarized by the following two dimensionless equations for estimating outside and inside track forces [12]:

$$R_{OT} = \frac{S^2.So}{2\mu_t.g.R^2.B}(B-2R) + R_\mu\left(\frac{1}{2} + \frac{S^2.R_{hB}}{gR}\right) + \frac{1}{2}\left(K^{=}\sin\theta + I^{=}\cos\theta\right)$$
$$+ R_{LB}\left(\frac{1}{4} + \frac{S_o^2}{L^2}\right) - \frac{1}{B}\left(K^{=}\cos\theta - I^{=}\sin\theta\right)(X+So) \text{ ………... (3)}$$

$$R_{IT}=\frac{S^2.So}{2\mu_t.g.R^2.B}(B+2R)+R_\mu\left(\frac{1}{2}-\frac{S^2.R_{hB}}{gR}\right)+\frac{1}{2}\left(K^{=}\sin\theta+I^{=}\cos\theta\right)$$

$$-R_{LB}\left(\frac{1}{4}+\frac{S_o^2}{L^2}\right)+\frac{1}{B}\left(K^{=}\cos\theta-I^{=}\sin\theta\right)(X+So) \qquad \text{.........} (4)$$

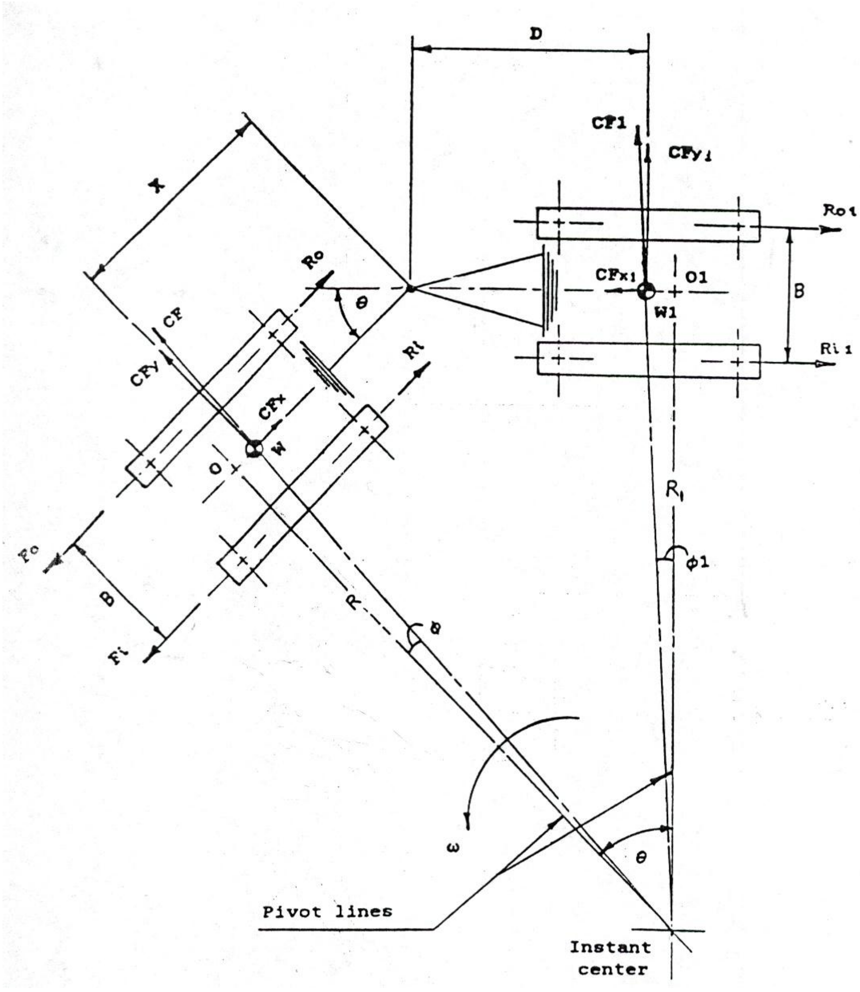

Figure (2) Schematic of tracked vehicle towing a tracked trailer during a turn at moderate or high speed

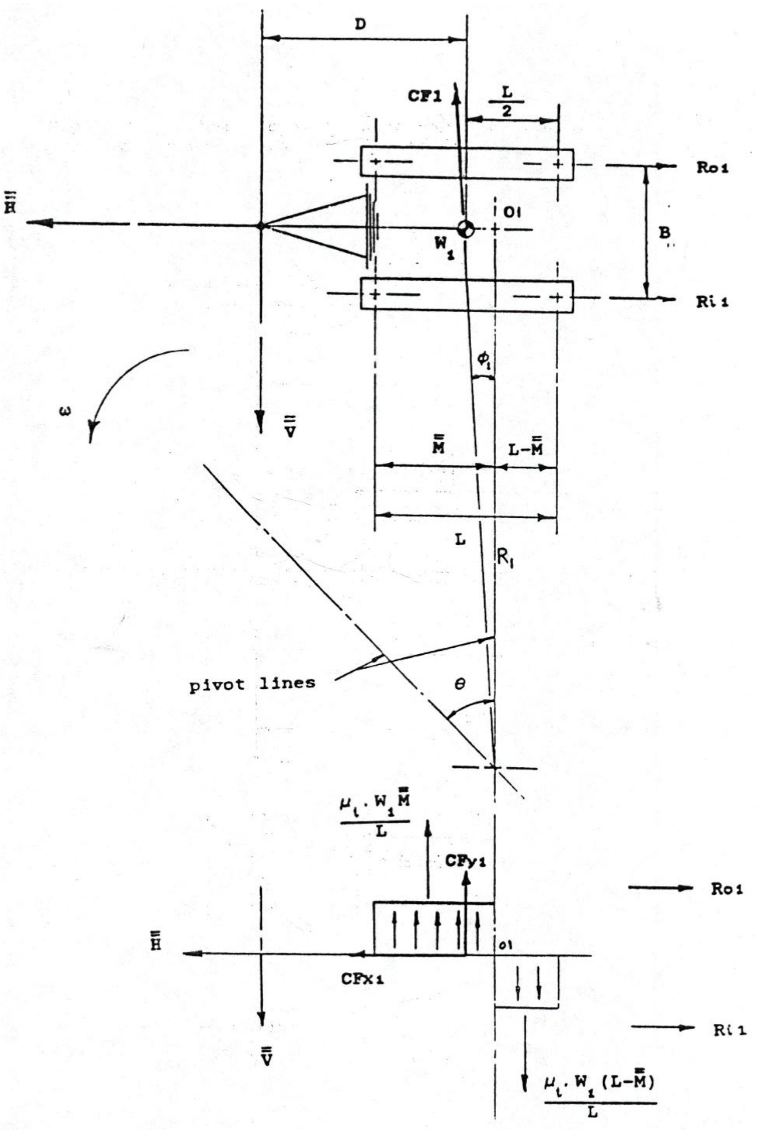

Figure (3) Schematic of forces acting on a towed trailer during a turn at a moderate or high speed

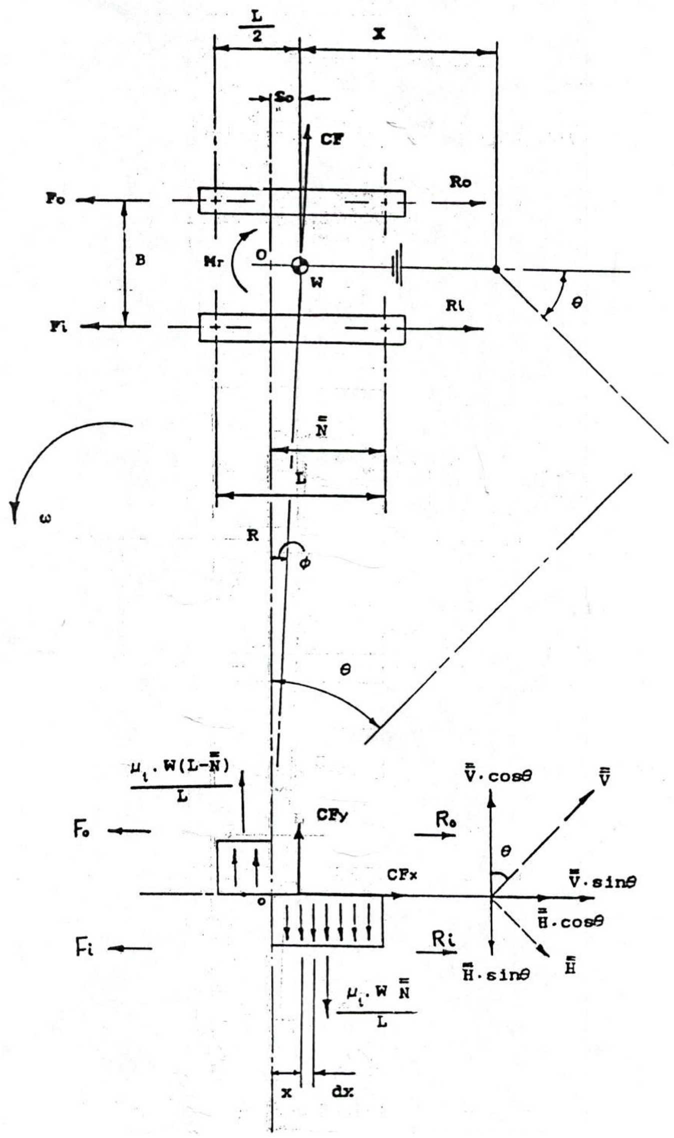

Figure (4) Schematic of forces of towing tracked vehicle during a turn at moderate or high speed

In order to compare Yahya's results with Wong's work with regard to centrifugal effect, the value of turning radius as a function of turning angle can be calculated using **Fig.(5)**. This can be summarized as follows:

$$R_1 = \frac{\left(M^{=} + D - \frac{L}{2}\right)}{\tan\theta} + \left[\frac{L}{2} \left\{ \frac{S^2}{\mu_t . g \left[R_1 \cos\theta + \left(M^{=} + D - \frac{L}{2} \right) \sin\theta \right]} + K^{=} \cos\theta - I^{=} \sin\theta \right\} + X \right] \frac{1}{\sin\theta} \quad \text{.... (5)}$$

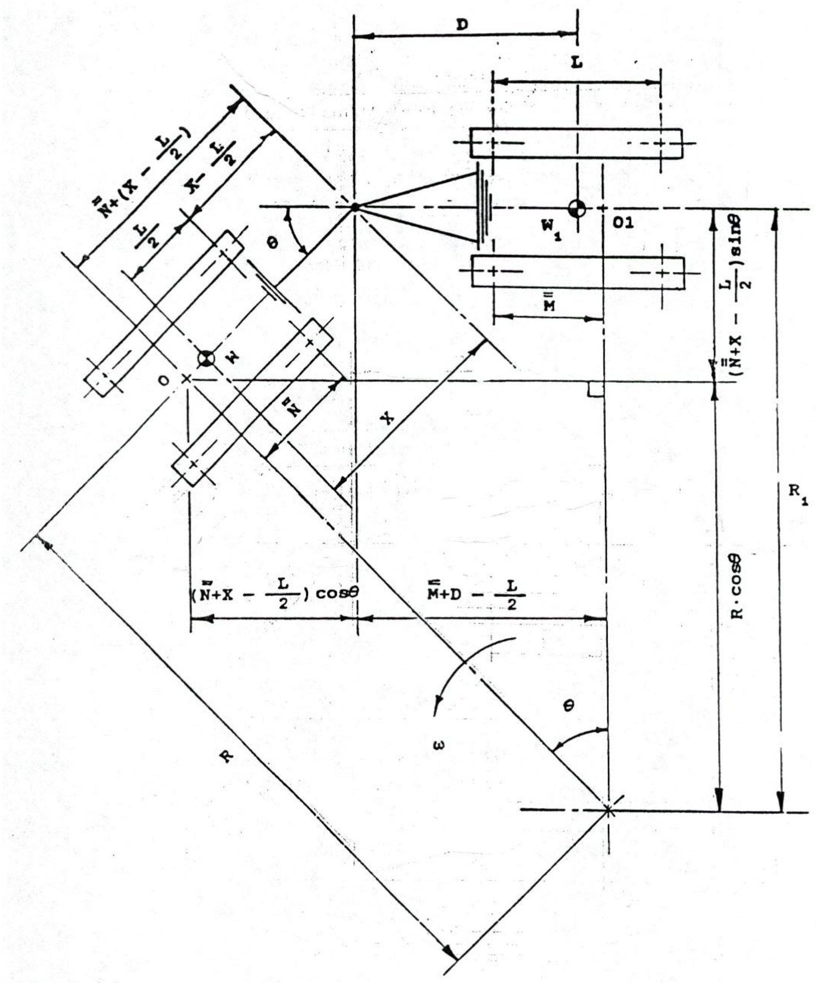

Figure (5) Schematic diagram of articulated tracked vehicle showing the value of radius of turn and steering angle during a turn

3. Results and Discussions

The following results were utilized for comparison studies between single tracked vehicles and articulated tracked vehicles, using the specifications below in **Table (1)**.

Description	Single Vehicle	Articulated Vehicle
Total weight (W)	20 ton	20 ton/unit
Height of C.G (h)	1.27 m	1.27 m/unit
Tread width (B)	2.46 m	2.46 m/unit
Contact length (L)	3.45 m	3.45 m/unit
Hitch length (D) to contact length (L) ratio (R_{DL})		1.5
Hitch length (X) to treat width (B) ratio (R_{XB})		0.7

At operational conditions from 0 to 25 km/hr speeds. **Table (1)**, used specifications for single and articulated tracked vehicles

The track forces at various turning radii with a particular velocity, and taking into account the centrifugal acceleration have been calculated. This was accomplished by using equations 1 & 2 for a single tracked vehicle, and, equations 3 & 4 for an articulated tracked vehicle. Vehicle speed up to 25 km/hr was used. The value of turning radius of towing vehicle can be evaluated using equation (5) at different value of steering angle from 0 to 90. The variation of track forces versus turning radius for a single tracked vehicle is shown in **Fig.(6)**. When the turning radius is small, the absolute value of both inside & outside track forces will be diminished as vehicle speed increases. However, when the turning radius becomes larger, the values of speeds and hence centrifugal acceleration have no affect what so ever on the track forces.

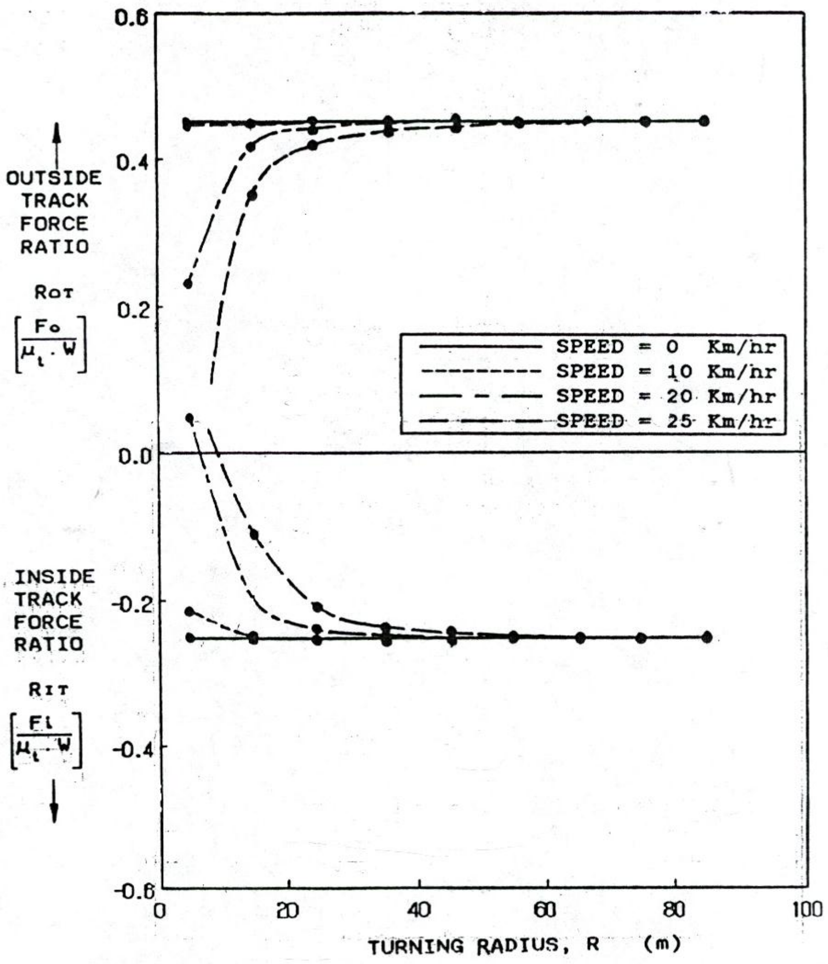

Figure (6) Variation of inside and outside track force ratio against turning radius for single tracked vehicle at different values of speeds when R_{LB} = 1.4, R_{DL} = 1.5, and R_{XB} = 0.7 during turning positions

With regard to the articulated tracked vehicle, the variation of track forces versus turning radius is shown in **Fig.(7)**. It can be seen that at a high vehicle speed, the outside track force decreases with increase in turning radius. Then, it tends to level off at lower values of turning radius. At small turning radius, the force becomes larger indicating vehicle immobilization. The variation of inside track force with turning radius shows that at lower vehicle speed, the inside track force decreases with increase in turning radius and then tends to level off. At higher vehicle speed, it increases a little, and then starts to decrease, eventually leveling off.

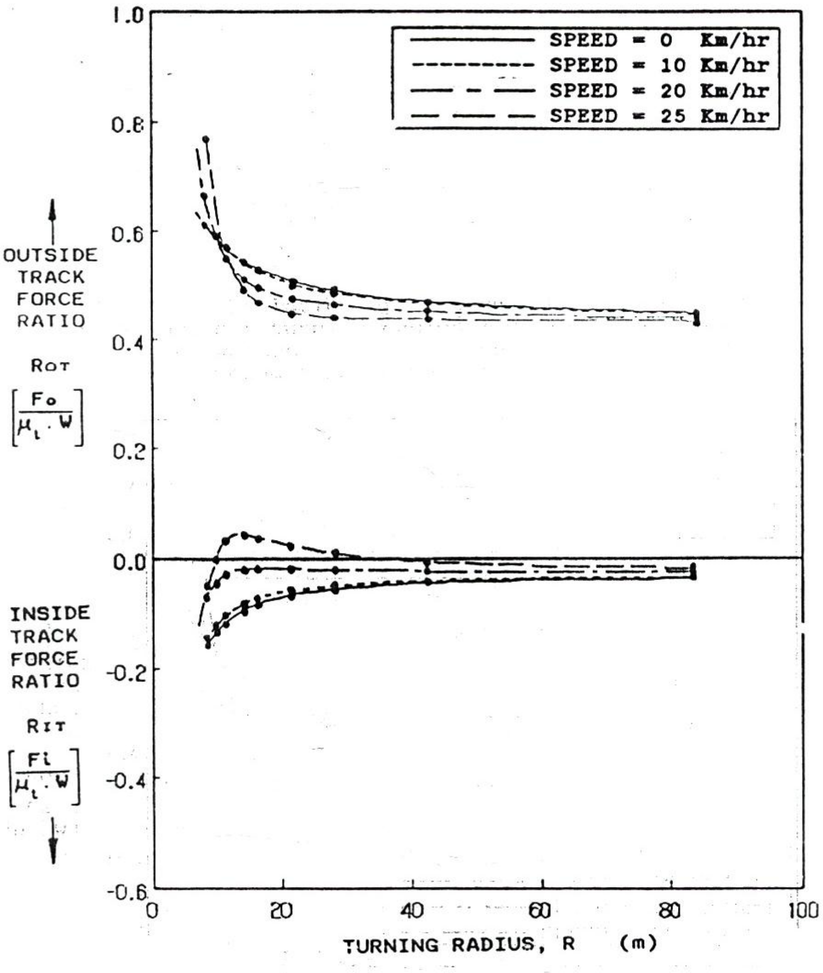

Figure (7) Variation of inside and outside track force ratio against turning radius for articulated tracked vehicle at different values of speeds when R_{LB} = 1.4, R_{DL} = 1.5, and R_{XB}= 0.7 during turning positions

When comparing steering analysis of single tracked vehicles with those of articulated tracked vehicles and in the presence of centrifugal force effect, it is essential to set each operational condition of the two cases on one dependent variable. This is shown in **Fig.(8)** where a speed of 25 km/hr was used for both cases. It is evident from this latest graph that the outside track force of articulated tracked vehicle decreases with the increase of turning radius up to a certain value, and then becomes less than that of a single tracked vehicle.

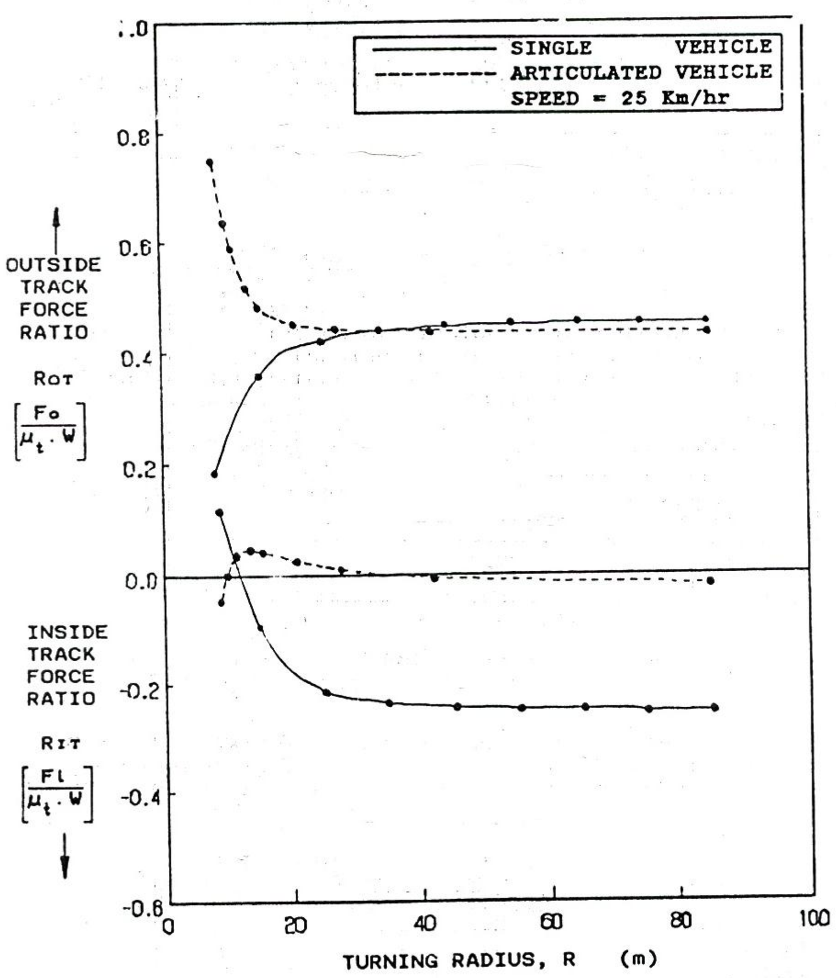

Figure (8) Comparison of inside and outside track force ratio against turning radius for single tracked vehicle and articulated tracked vehicle when R_{LB} = 1.4 R_{DL} = 1.5, and R_{XB}= 0.7, W=W_1 at speed = 25 km/hr

4. Conclusion

Generally when taking into account the centrifugal force effect, the required track forces for steering are significantly smaller for articulated tracked vehicles than those for single tracked vehicles. In comparison with a single tracked vehicle at high speeds, there are less required forces for articulated tracked vehicle. This is always true especially when turning radius is not very small. On the other hand, at low speeds and at small values of turning radius, the outside track forces needed for single tracked vehicles, are less than that for articulated tracked vehicles. On the contrary, the required inside track forces for single tracked vehicles are always greater than those of articulated tracked vehicles at any value of turning radius. So as a result, the behavior of articulated tracked vehicles in the presence of centrifugal acceleration was improved at higher speed especially those of the inside track forces. However, the improvement in the outside track forces is occurred up to moderate and higher values of turning radius. So, as a result, the percentage effect of centrifugal forces on steering could be very high, leading to great improvement for steering of articulated tracked vehicles.

5. References

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Notations

B	Width of both the towed and towing tracked vehicle
CF_1	Centrifugal force for the towed tracked vehicle
CF_{x1}	Centrifugal force component along the x axis of the towed tracked vehicle
CF_{y1}	Centrifugal force component along the y axis of the towed tracked vehicle
CF	Centrifugal force of the towing tracked vehicle
CF_x	Centrifugal force component along the x axis of the towing tracked vehicle
CF_y	Centrifugal force component along the y axis of the towing tracked vehicle
D	Distance between the hinge point and center of gravity of the towed vehicle
F_o	Outside track force for the towing tracked vehicle
F_i	Inside track force for the towing tracked vehicle
g	Acceleration due to gravity
h	Height of center of gravity of the vehicle
H	Longitudinal hinge force component
I	Dimensionless factor representing $H^{=} / (\mu_t W)$
K	Dimensionless factor representing $V^{=} / (\mu_t W)$
L	Track length of both the towed and towing vehicle
M	Distance between pivot line and front end of the towed tracked vehicle
M_r	Moment of turning resistance
N	Distance between pivot line and rear end of the towing tracked vehicle
R_{OT}	Dimensionless factor representing $Fo / (\mu_t W)$
R_{IT}	Dimensionless factor representing $Fi / (\mu_t W)$

R_{LB}	Dimensionless factor representing L/B
R_{XB}	Dimensionless factor representing X/B
R_{DL}	Dimensionless factor representing D/L
R_{hB}	Dimensionless factor representing h/B
R_{O1}	Motion resistance of the outside track of the towed tracked vehicle
R_{i1}	Motion resistance of the inside track of the towed tracked vehicle
R_o	Motion resistance of the outside track of the towing tracked vehicle
R_i	Motion resistance of the inside track of the towing tracked vehicle
R_μ	Dimensionless factor representing μ_r / μ_t
R	Turning radius of the towing tracked vehicle
R_1	Turning radius of the towed tracked vehicle
S	Tracked vehicle Speed during turning
So	Distance between pivot line and center of gravity of the towing tracked vehicle
V	Lateral hinge force component
W	Gross weight of the towing tracked vehicle
W_1	Gross weight of the towed tracked vehicle
X	Distance of the hinge point to the center of gravity of the towing vehicle
θ	steering angle
μ_t	Coefficient of lateral skidding friction
μ_r	Coefficient of longitudinal friction