IJSRA

International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

Computational modelling of tyre behavior on concrete and sandy soil surfaces using solid works software

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International Journal of Science and Research Archive, 2024, 12(01), 030–036

Publication history: Received on 16 March 2024; revised on 27 April 2024; accepted on 30 April 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.1.0698

Abstract

Tyres are integral components of vehicles, crucial for controlling movement, supporting vehicle weight, and providing traction. Consequently, there's a growing need for accurate tyre modelling to optimize performance under varying conditions. While extensive literature exists on tyre-soil interaction, information is scarce regarding tyre behaviour across different soil types. This study aims to address this gap by employing computational modelling techniques to analyse tyre behaviour on two distinct surfaces: concrete and sandy soil. Utilizing SolidWorks software, a comprehensive investigation was conducted to evaluate tyre performance under varying road conditions. The study focused on analysing shear forces, soil resistances, and partial soil resistant forces exerted on the tyres. The findings indicate that tyres exhibit superior performance on concrete surfaces compared to sandy soil. The computational simulations predicted shear forces of 0.6 kN, soil resistances of 0.2 kN, and partial soil resistant forces of 0.25 kN for the concrete surfaces. These results were notably higher than those observed on sandy soil surfaces. This study sheds light on the intricate dynamics of tyre behaviour under different road conditions and underscores the importance of computational modelling in understanding and optimizing tyre performance. The insights gained from this research have significant implications for vehicle design, road engineering, and the development of more efficient and durable tyres tailored to specific environmental conditions.

Keywords: Tyres; Sandy soil; Concrete surface; Modelling

1. Introduction

Tyres play an important role in every vehicle setup. Tyres are found beneath vehicles, and they control the movement and take up the vehicle's weight as the air-filled structure provides a cushion [1]. It also provides traction force for the vehicle. According to Kim et al. [2], tyres determine a vehicle's behaviour since principal external forces are caused by the interaction between the tyre and the road surface. This is vital for the dynamic behaviour of the vehicle [2]. Therefore, it is paramount that tyres are always in good shape and free from any obstruction that can potentially harm their behaviour. Hjort and Anderson [3] hold that when vehicles are also equipped with the wrong tyres, the risk of rod crash accidents is high. Again, tyres are made from rubber, which is prone to receive external shocks and perforation from obstacles on the road surfaces, which when unseen can be catastrophic to the vehicle and its occupants. Pacejka [4] reiterates that vibrational characteristics and large deflection caused to the tyres as a result of the condition of the road and cause ride discomfort. Tyres must be well taken care of and properly maintained, lack of care can be deadly. This also means that the road surfaces are also considered. Wong [5] postulates that when tyres are on the road, the contact patch of a tyre is the sliding region and the adhesive region. These regions depend on the condition of the road surfaces.

According to Grip [6], road surfaces influence the performance of tyres as driving the vehicle on a road not designed for the actual conditions can lead to vehicular crashes and cause detrimental effects on the environment through the

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emission of rubber particles due to wear on their threads. The condition of the road surfaces is mostly beyond the influence of the tyres or the driver. Typically, road surfaces were designed to be smooth or rough depending on the environment and the purpose of the road. However, as time progresses, continuous use of the road by both vehicles and other road users deteriorate the road and this tends to become problematic to all the users. Grip [6] underpins that bad road surfaces can cause tyre wear. According to Liu et al [7], the characteristics of the road surfaces in terms of coarseness and sharpness also have a major impact on tyre wear.

Tyre performance is also affected by the forces acting on them either stationary or in motion. According to Taheri [8], all forces and moments needed for driving, braking and cornering are all transferred between the vehicle and the road through the tyre. These forces and moments play a role in influencing the behaviour of the tyres on the road [9]. For instance, higher forces as a result of high velocities and friction can affect the tyres' abilities to steer and control the vehicle [10]. As the forces and moments on the tyres are not readily known, it becomes important that analyses are carried out on both the tyres and the road surfaces.

Modelling tyres helps to suitably design and analyze their behaviour, which can aid in minimizing some of the challenges they encounter on the road. Wong [5] emphasised the importance of predicting wheel performance with a focus on traffic conditions on loosened soil. Many researchers have concentrated on the pressure-plate sinkage theory to predict the traction parameters of the wheels [11]. However, this theory does not provide accurate information when applied to wheels in motion on the soil. The semi-empirical off-road tyre model, which was proposed by [12] deals with off-road operations and centres on soft soils. The model fails to capture other soil types, hence sufficient information about the condition of other soils cannot be accurately anticipated by the model. The tyre-soil system model by [13], concentrates on main traction forces at the partial contact areas located at the three-dimensional contact areas of the tyre with the soil. The model has little information on various types of road surfaces, with which the tyres sometimes are in contact. The Finite Element Model used by [14] was extensive on traction, braking, and negotiating with little focus on different road surfaces. Du et al. [15] used the Discrete Element Method to simulate tyre steering on sandy soil. This approach fails to recognise the other road surfaces.

A vast literature exists for modelling and simulating tyre behaviour on road surfaces using different software to do the prediction. The majority of these works have centred mainly on the interaction between the tyre and only one kind of soil. It is, however, difficult to access information on the tyre interaction between different soil types, and those that exist scarcely go into more than two soil types. To grasp a deeper knowledge of tyre behaviours and conditions under different soil types, there must be a comprehensive study to model tyres on different road conditions to understand the outcome.

The objective of this study was to model tyres under concrete, and sandy soils to investigate their behaviour and performance using SolidWorks software.

2. Methods

2.1. Tyre and soil interaction

Based on the assumption proposed by [17], the traction forces are determined by wheel movement theories. The traction forces take into consideration tyre deformations. The main traction forces are determined at the partial contact areas located at the three-dimensional contact of the tyre with the road surface. Figure 1 shows the force distribution at the single partial contact area [13].

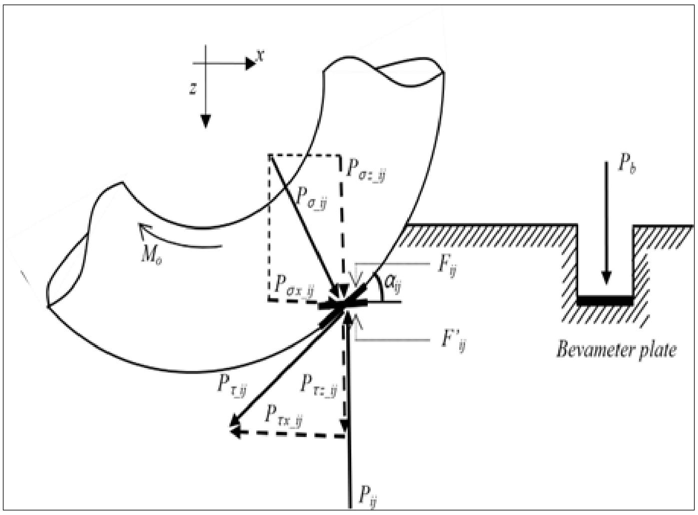

Figure 1 Force distribution at the single partial contact area on the three-dimensional contact [13]

The shear force (Pij), soil resistance force (Pij), and partial soil resistance forces acting on the partial contact areas were determined by the approaches used by [13],[16],[17], with little modifications.

The shear forces at the analysed partial contact areas were computed using Equ. 1.

$$\mathrm{Pij} = (\sigma ij \;\cdot tg\phi + \; c\,)[1 - e - j/k].Fij \;\; (1)$$

Where;
$P_{\tau ij}$ = the shear forces at the analysed partial contact areas (kN),
F_{ij} = the partial contact areas at the three-dimensional contact area of the tyre with the soil (cm^2).

Equation 2 was used to determine soil resistance forces.

$$Pij \;=\; P\sigma zij \;+ P\tau zij \ldots\ldots..(2)$$

Where;
P_{ij} = soil resistance forces (kN),
$P_{\tau zij}$ = vertical components of the shear forces $P_{\tau ij}$ (kN),
$P_{\sigma zij}$ = vertical components of the normal forces $P_{\sigma ij}$ (kN).

The partial soil resistance forces acting on the partial contact areas were calculated with Equ. 3.

$$\mathrm{Pij} \;=\; F'ij \;\cdot k \;\cdot \lambda x - 2\left(\frac{hpj}{bp}\right)^{n} \ldots\ldots.(3)$$

Where;
Pij = partial soil resistance forces acting on the partial contact areas (kN),
hpj = depth in the rut of the partial contact areas (cm),
λ = geometrical scale characterizing the plate surface and tyre surface (-),
x = exponent characterizing scale of forces (-),
Fij = horizontal projection of the partial contact areas Fij (cm^2).

2.2. Modelling procedure

The modelling started with the creation of geometry. The drawing was exported into SolidWorks software after creation. The part modules were drawn and accepted after subjecting them to analysis. The modules were then brought together to constitute the complete assembly. Figure 2 shows the processes.

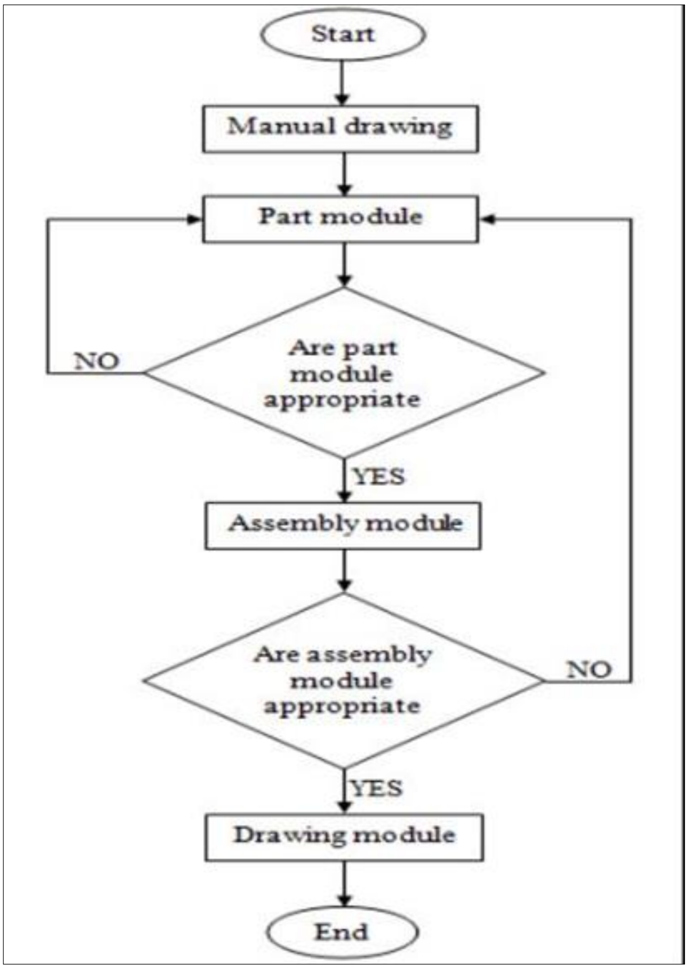

Figure 2 Flow chart in modelling using SolidWorks [18]

2.3. Tyre specifications

The tyre was modelled to carry the following specifications. These specifications help the characteristics of the tyre to be known and ensure the required vehicle's use of the tyre [19]. Figure 3 shows the modelled 185/55 R15 81H road tyre; Nominal section Width = 185 mm.

Nominal Aspect Ratio = 55 (tyre height is 55 % of tyre width).

Rim Diameter Code = 15 inches.

R = Radial Tyre.

Load index = 81.

Speed rating = H.

Figure 3 Modelled Road tyre with SolidWorks

2.4. Modelled Tyre on sandy soil

The modelled tyre on sandy soil is shown in Figure 4. Sand is regularly characterised as granular material and solid [20]. When the wheel is on the ground, it comes into contact with the sand particles and this is the point of contact, which allows the tyre to move.

Figure 4 Modelled tyre on sandy soil with SolidWorks

2.5. Modelled tyre on concrete road

Concrete surfaces tend to have the particulates closely packed, hence a good structure to resist external forces such as compressive forces of the vehicle tyres and feet of pedestrians. Figure 5 shows the tyre on a concrete floor.

Figure 5 Modelled tyre on a concrete surface

3. Results and Discussion

Table 1 Forces in the soil as influenced by tyre contact

Forces created by tyre on the soil surface	Sandy Soil	Concrete road
Shear forces (kN)	0.4	0.6
Soil resistance forces (kN)	0.09	0.2
Partial soil resistance forces (kN)	0.1	0.25

The shear forces induced in the sandy soil are lesser than that of the concrete floor as the particles of sandy soils are not closely packed together Lu et al [21], and hence have a loose structure. With the concrete floor, the shear forces were greater as the particulates of the road are closely packed such that, any force trying to shear them is greatly resisted. This indicates that slip will be minimised when the tyre is on the concrete road as against the sandy road. This conforms to the conclusion drawn by Rasmussen et al. [22] that slip is minimised between the tyre and the concrete road. Soil resistance force with the sandy soil was predicted at 0.09 kN as against the 0.2 kN given by the concrete floor. Soil resistance force determines how soil impedes the movements of the tyre in the soil and its ability to withstand deformity when under load [10]. Equally, with the partial soil resistance forces, the sandy soil had 0.25 kN, which was higher than the value recorded by the concrete road.

4. Conclusions

A 185/55 R15 81H tyre was modelled to ply on two road surfaces. The tyre showed great signs against the shearing force on the concrete road, which meant the tyre would likely face little slip and that would translate into less fuel consumption of the vehicle. The tyre also exhibited good signs against soil resistance forces and partial soil resistance forces of 0.2 and 0.25 kN, respectively, on the concrete surface, which could potentially ensure that the tyre will not sink when plying on a concrete surface.

Compliance with ethical standards

Disclosure of conflict of interest

Authors' declare that there is no competing conflict of interests

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