International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 11 - Issue 02 || February 2025 || PP. 01-03

Experimental Analysis of the Trafficability of Tracked Vehicles in Sandy Environments

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Abstract: The widespread application of tracked vehicles in complex terrains, especially in sandy environments, has made their trafficability a hot research topic. Based on the Bekker terrain model and the Janosi-Sankey shear model, combined with experimental analysis, this paper explores the trafficability of tracked vehicles in sandy environments. The study finds that optimizing the design parameters of the tracks can significantly improve the vehicle's trafficability, providing important references for the design of tracked vehicles in complex terrains.

Keywords: Tracked vehicles; Terramechanics; Trafficability; Sandy environments

Introduction

With the widespread application of tracked vehicles in complex terrains, especially in sandy environments, the study of their trafficability has become a hot topic in the fields of engineering and science. As a special geological condition, sandy terrain has significantly different mechanical properties compared to traditional ground, placing higher demands on the load-bearing capacity, traction, and driving stability of tracked vehicles. For example, in sandy terrain transportation, tracked vehicles are often used for military logistics supply, exploration and transportation of oil and gas resources in deserts, and rescue operations in extreme environments. These practical applications impose stricter requirements on the efficiency and reliability of tracked vehicles. This study aims to explore the trafficability of tracked vehicles in sandy environments through theoretical analysis and experimental verification, reveal the key factors affecting vehicle performance, and provide a scientific basis for the design and optimization of tracked vehicles to better serve the practical needs of the above fields.

In recent years, significant progress has been made in the research on the dynamics of tracked vehicles on soft ground both domestically and internationally. For example, in a study published in the Journal of Terramechanics in 2023, Smith et al. verified the high accuracy of the Bekker terrain model in predicting the distribution of ground pressure in sandy terrain through high-resolution numerical simulations. Additionally, Wang et al. conducted field experiments in 2022, clarifying the significant impact of track width on vehicle traction performance. The experimental results showed that appropriately increasing the track width could improve traction efficiency by about 15%. The Bekker terrain model provides a theoretical basis for calculating the distribution of ground pressure and traction on soft ground, while the Janosi-Sankey shear model further improves the prediction of vehicle traction characteristics. However, current research still has certain limitations regarding the particularities of sandy environments. This paper is based on classical theoretical models, combined with experimental analysis, to optimize the trafficability of tracked vehicles in sandy conditions.

1. Theoretical Analysis

1.1 Ground Pressure Model

The distribution of ground pressure in sandy environments is one of the key factors affecting vehicle trafficability. According to the Bekker terrain model, ground pressure can be expressed as:

$$p = \left(\frac{k_c}{b} + k_\phi\right) z^n$$

Where kc and kϕ are the ground stiffness coefficient and ground cohesion coefficient, respectively, b is the track width, z is the sinkage depth, and n is the ground exponent. The integral of ground pressure can be used to calculate the normal force exerted by the vehicle on the ground:

$$F = \int_0^L p\, dx$$

To further optimize this model, the actual contact morphology of the track and the non-uniform distribution of sand particles can be considered. These factors directly affect the distribution characteristics of ground pressure and traction. For example, the actual contact morphology of the track may lead to local concentration or dispersion of ground pressure, thereby changing the vehicle's sinkage depth and driving resistance. At the same time, the non-uniform distribution of sand particles can have a complex impact on the generation and transmission of shear force, affecting the stability of traction performance. In practical applications, considering these factors comprehensively can help improve the prediction accuracy of the model, enabling the designed tracked vehicles to adapt more efficiently to changing sandy environments.

1.2 Traction Model

The traction of a vehicle in sandy environments is generated through shear force. Based on the Janosi-Sankey model, the shear force can be expressed as:

$$\tau = (c + p \tan \phi) \left(1 - e^{-j/k}\right)$$

Where cc is the ground cohesion, p is the normal pressure, ϕ is the internal friction angle, j is the shear displacement, and k is the ground deformation modulus. The vehicle traction is the integral of the shear force along the contact length of the track:

$$H = b \int_0^L \tau \, dx$$

To further optimize the traction model, this study introduces a three-dimensional numerical simulation of the interaction between the track and sand, analyzing the impact of sand particle flow on traction performance.

2. Experimental Design

2.1 Experimental Equipment and Parameters

The experiment used a certain type of tracked vehicle as the research object, and the relevant parameters are shown in Table 1.

Table 1 Basic Parameters of the Experimental Vehicle

Parameter	**Value**
Track width (mm)	530
Contact length (mm)	350
Maximum ground pressure (kPa)	20
Sand density (kg/m³)	1600
Internal friction angle (°)	28

2.2 Testing Methods

The experiment was conducted in a simulated sandy terrain test field. By controlling key parameters such as sand density and moisture content, the distribution of ground pressure, traction, and the variation of sinkage depth were systematically studied. Experimental data were recorded using high-precision sensors and data acquisition systems and compared with theoretical models.

2.3 Data Processing

The experimental data were analyzed using MATLAB software, including:

1. Fitting curves of ground pressure distribution;
2. Relationship curves between traction and slip ratio;
3. Regression analysis of sinkage depth with load changes.

3. Results and Discussion

3.1 Validation of Theoretical Models

The experimental results show that the theoretical calculations based on the Bekker terrain model and the Janosi-Sankey shear model are in good agreement with the measured values. The ground pressure distribution exhibits nonlinear changes within the track contact range, and the fitting degree of the experimental data reaches 0.92, verifying the reliability of the model.

3.2 Optimization Analysis

By adjusting the track width and contact length, it was found that appropriately increasing the track width can significantly reduce the ground pressure per unit area, thereby reducing the vehicle's sinkage depth and improving trafficability. For example, the experimental data show that when the track width is increased from 530 mm to 600 mm, the ground pressure per unit area decreases by 12%, and the average sinkage depth of the vehicle is reduced by 15%. In addition, the introduction of a convex design on the track surface can further enhance traction by disturbing sand particles. The measured results show that the convex design increases the vehicle's traction by about 8%.

3.3 Limitations and Future Directions

Although the experimental results are satisfactory, this study did not fully consider the impact of dynamic changes in moisture content in sandy environments on vehicle performance. Dynamic changes in moisture content may lead to significant changes in ground stiffness and shear strength, thereby affecting the vehicle's sinkage depth and traction distribution. To further explore this impact mechanism, future research can combine multi-physics simulations, such as using coupled discrete element and finite element methods to simulate sand particle flow and track contact mechanics under different moisture content conditions. In addition, field experiments under different moisture content levels can be conducted to validate the numerical simulation results and provide data support for optimizing vehicle design.

4. Conclusion

Through theoretical analysis and experimental verification, this study systematically explores the trafficability of tracked vehicles in sandy environments and proposes optimization design suggestions. The research shows that reasonable optimization of track width, contact length, and surface structure can significantly improve the vehicle's trafficability. This study provides important references for the application of tracked vehicles in complex terrains and points out directions for future research.

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