JIN DAWEI
ZHU JIANXIN
LI XIANG
and
ZHANG CHUNHUA

Analysis on the tractive performance of lunar rover wheel on soft sands

It is very important for exploring that the lunar rover enhances the tractive performance. Tractive performance could be measured by these parameters such as sinkage, drawbar pull, driving torque, motion resistance and slip when the lunar wheels move. The parameters could be gotten by soil bin test. The soils in the bin are mined in volcano. The variation of the parameters with the vertical load and velocity is analyzed in the paper, slip ratio is below 18%, the motion resistance increases with the velocity, but slip ratio is greater than 18%, the parameter decreases with the increasing velocity. Meanwhile, the rutting of the wheel of lunar rover is simulated by FEM.

Keywords: Lunar rover, drivingwheel, mechanical parameters, tractive performance

1. Introduction

The lunar is the planet which is the nearest to the earth, and the unique natural satellite of the earth. It is the important part of space activity that how explores the lunar's resourses. Lunar rover plays an key role in search mission for the lunar. Lunar rover is a space vehicle which can move, sample, carry on the surface of the lunar rover. In order to meet the requirement of searching, lunar rover must have better passing ability. The lunar surface is covered with regolith and the gravity is 1/6 in comparison with the earth. The wheel of lunar rover sinks, slips easily and even cannot move on the surface of lunar. Obviously, it is difficult that the lunar rover works normally under this condition. Because the wheel of lunar rover has a direct contact with lunar surface, the wheels are important for the moving of lunar rover. When lunar rover is moving, the wheels need bearing total weight of lunar rover, overcoming resistance and generate drawbar pull. At the same time, the wheels affect the ractive performance and mobility of lunar rover deeply. Thus, the analysis of mechanical relation between the lunar wheel and regolith has important significance for studying the tractive performance of the lunar rover[1-3].

Messrs. Jin Dawei*, Zhu Jianxin, Li Xiang, Zhang Chunhua, Aviation University of Air Force, Changchun 130022, China
*Corresponding author

Practically, the parameters are used to measure tractive performance, such as sinkage, drawba pull, driving torque and motion resistance. A great deal of researches is conducted for the tractive performance of lunar rover in the world. However, most of research concentrated on theoretical study. As far as the diameter and width of lunar rover wheels for concerned, sinkage is predicted by the formula of pressure[4]. The limit of the width of wheel, vertical load and slip are analyzed, and the formula of sinkage is corrected[5]. Reece-wang model is also corrected from the angle of elastic modulus and the maximum stress angle[6]. Actually, the tests are the most efficient methods for terrain-mechanics, because of the limited conditions, the tests are conducted under the scaled condition[7-8].

In this paper, in order to get the data and the mechanical parameters are analyzed directly, the massive tests are conducted in lunar-soil bin. These parameters gotten from lunar soil-wheel test bin are analyzed with different velocities and vertical loads, and the rutting is simulated by FEM. The results provide theoretical basis and reference for analyzing mobility of lunar wheel and optimizing the structure of the lunar wheel.

2. Soil bin test

2.1. The lunar soil simulants used for the test

JLU-2 lunar soil stimulants is used in the test. Table 1 shows the mechanical parameters of JLU-2 lunar soil stimulant.

2.2 Lunar soil –wheel test bin

The lunar soil-wheel test bin used in the test is studied by key laboratory of bionic engineering of Jilin University, as shown in Fig.1. In order to meet design's demand, the test system of soil bin consists of mechanical system and electronic system, as shown in the Fig. 1-1 . The soil bin is fixed, test wheel can move in the mechanical system. The electronic system can measure sinkage, angle displacement, torque of driving wheel, displacement of wheel. To apply light load and decrease friction, the structure of system is simplified and the range of sensors is very small.

Table 1. Mechanical parameters of JLU-2 lunar soil simulants

Deformation index n	Cohesive modulus k_c (N/cm^{n+1})	Frictional modulus k_φ(N/cm^{n+2})	Bulk density γ [g/cm^3]	Cohesion c [kPa]	Shear modelus k_j [cm]	Particle density [g/cm^3]	The internal friction angle φ [°]
0.96	1.99	0.45	1.26	0.32	1.59	2.73	30.19

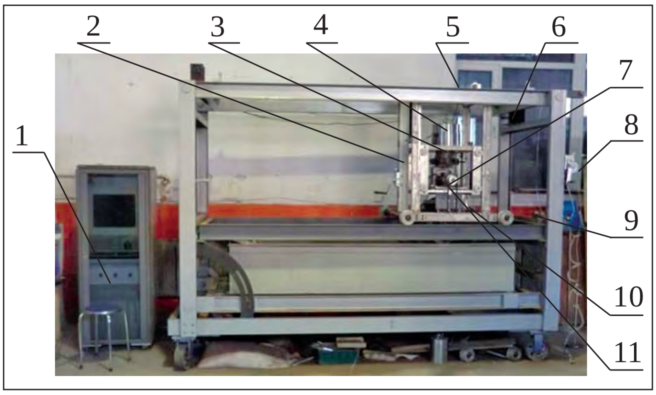


Fig. 1. Lunar soil-wheel test bin
1-Industrial control box, 2-lifting gear, 3-vertical loading weight, 4-additional weight, 5-vertical displacement sensor, 6-horizontal displacement sensor, 7-frequency variable motor , 8-resistance control weight, 9-draw bar pull sensor, 10-test wheel, 11-pressure sensor

2.3 Test wheel

The test wheel is rigid wheel and made of aluminum alloy, as shown in Fig. 2. The wheel has a diameter of 300 mm and width of 150mm.

Fig. 2. The test wheel

2.4 Test index

Sinkage, driving torque, drawbar pull and motion resistance. The former three quantities could be measure directly; the last quantity could be computed by the measured quantities. The following equation could express motion resistance.

$$F = T/r - DP \quad (1)$$

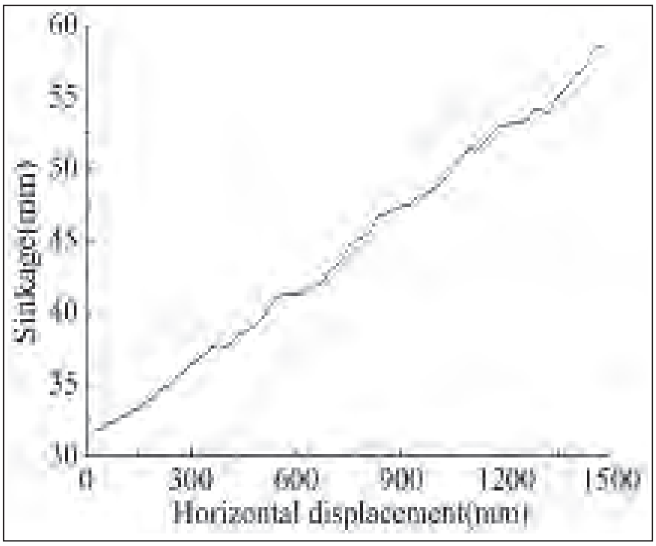
In the equation, T is driving torque, DP is drawbar pull, r is the radius of test wheel.

Fig. 3. The rutting in lunar soil simulants

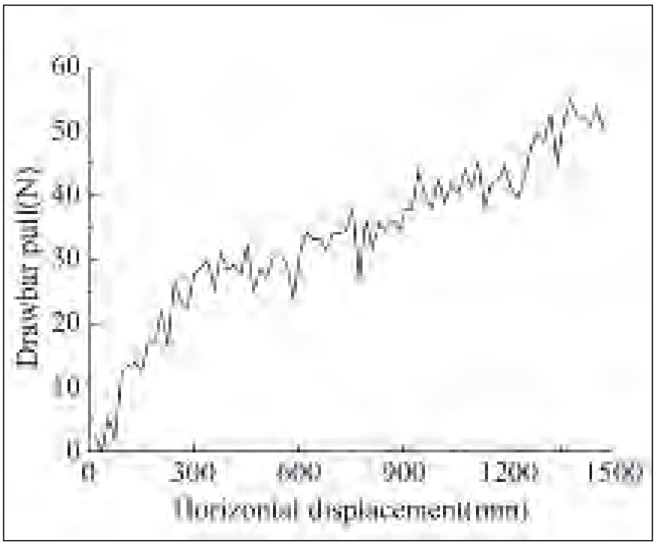
2.5.The test and the data

The test wheel could destroy the lunar soil stimulants as the test wheel moves in the soil bin, as shown in Fig. 3. At the same time, the sensors in the test system can measure the test indexes. In the test, sinkage is measured by vertical displacement sensor. Drawbar pull is measured by pressure sensor and also by torque sensor. Motion resistance is computed by Eq.1. The data measured is shown in Fig. 4. In this case, the velocity of test wheel is 35mm/s, vertical loading is 300N, slip ratio varies from 0 to 60%.

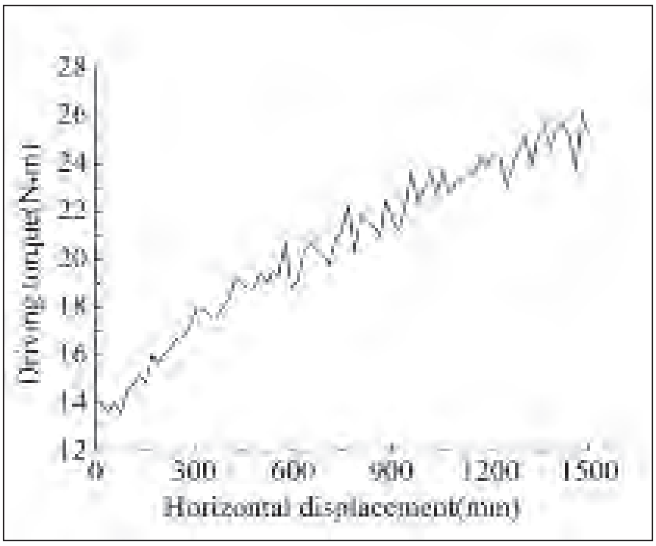
In Fig. 4, it can be seen clearly that the four parameters regularly fluctuate with the displacement increases. The reason is for the test wheel with lugs. The forces acting on the lunar soil stimulant regularly change when the lugs of the test wheel enter into the lunar soil stimulant in turn. Meanwhile, the reactions exerted on the wheel surface by the lunar soil stimulant regularly change. Thus, sinkage, drawbar pull, driving torque and motion resistance regularly vary also. At the same time, it can be found that the four parameters are increased with the increase of dispacement, actually, they are increaed with the increase of slip ratio, because the slip ratio vary continuously during the moving of the teat wheel.



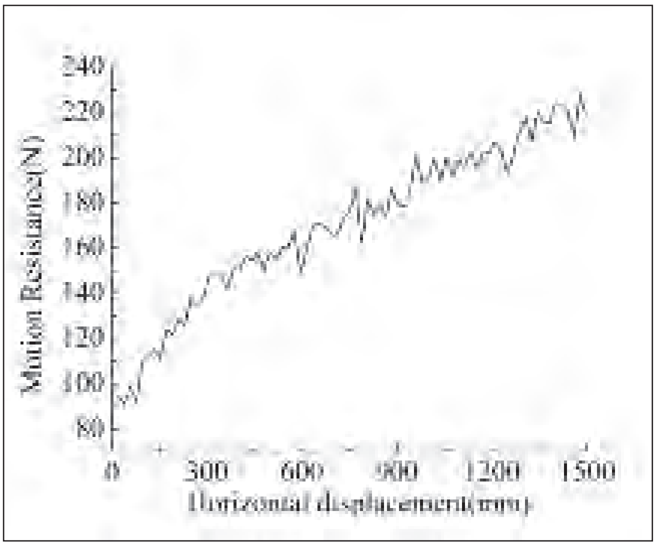
(a)



(b)



(c)



(d)

Fig. 4: Variation of the data measured with the test wheel's displacement

3. The analysis of test result

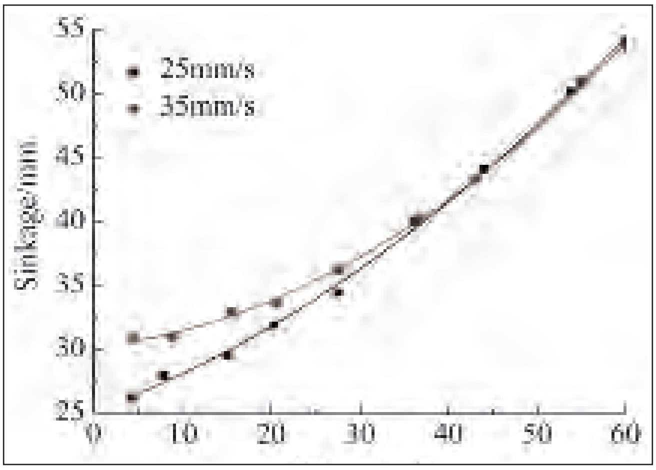
3.1. The effect of velocity on tractive performance

Fig. 5 shows the influence of the velocity on sinkage, drawbar pull, driving torque and motion resistance under the load of 200N. In Fig. 5(a), it can be seen that sinkage increases with the increasing of slip. When the slip ratio is below 38%, sinkage increases with the increasing of velocity. The largest difference is 5mm, and the difference become small with the increasing of slip ratio. When slip ratio is greater than 38%, no significant difference is observed between the two curves. The results in Fig. 5(a) suggest that the change of velocity has slightly on the sinkage when slip ratio is greater than 38%.

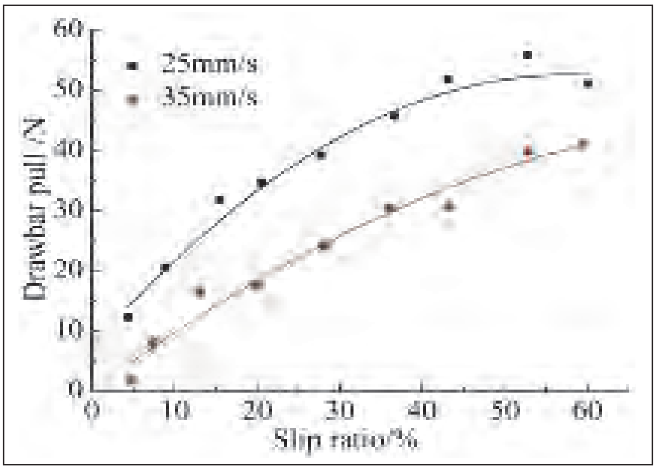
In Fig. 5(b), the curves show the relationship between drawbar pull and slip ratio. It can be seen that drawbar pull increases with the increasing of slip ratio, meanwhile, drawbar pull increases with the decreasing of slip ratio. When slip ratio equals 35%, the difference reaches maximum, and the drawbar pull at the speed of 25mm/s increases by 37%. Fig. 5(b) indicates that the smaller velocity can cause larger drawbar pull, and the influence of velocity on draw bar pull must be considered when studying.

The curves in the Fig. 5(c) show the relationship between driving torque and slip ratio. It can be observed that the driving torque increases with the increasing of slip ratio. With the increasing of velocity, the driving toque is increased slightly, and the driving torque is at the speed of 35mm/s by 6.2%-12% than that at the speed of 25mm/s. The result indicates the influence of velocity on driving torque is stable.

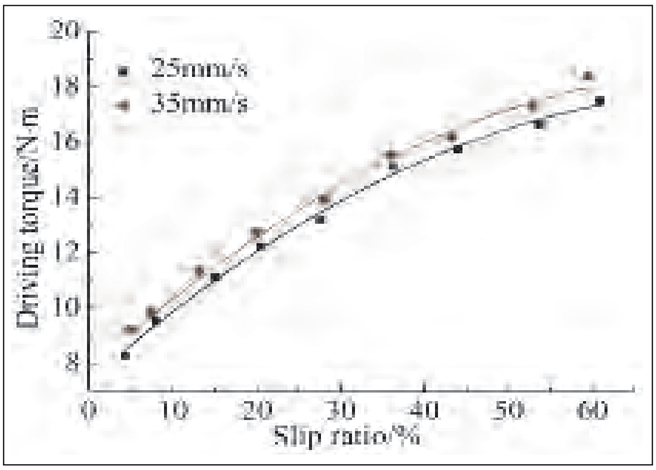
In Fig. 5(d), the curves show motion resistance increase with the increasing of slip ratio. When slip ratio is below 13%, motion resistance increases with the increasing of velocity, however motion resistance decreases with the increasing of velocity when slip ratio is greater than 13%. The maximum increase of motion resistance at 25mm/s is increased by 23% than that at the speed of 35mm/s. The result means that such more soil stimulant heaps up before the test wheel than that the larger motion resistance occurs when the test wheel has a lower velocity.



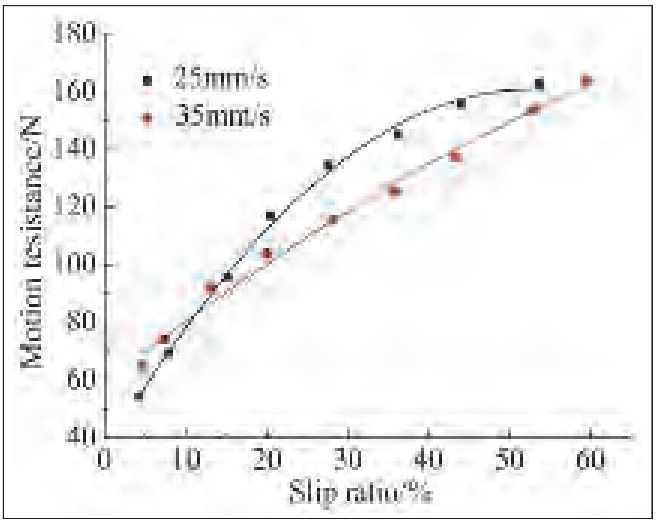
(a) The variation of sinkage with slip ratio



(b) The variable of drawbar pull with slip ratio



(c) The variation of driving torque with slip ratio



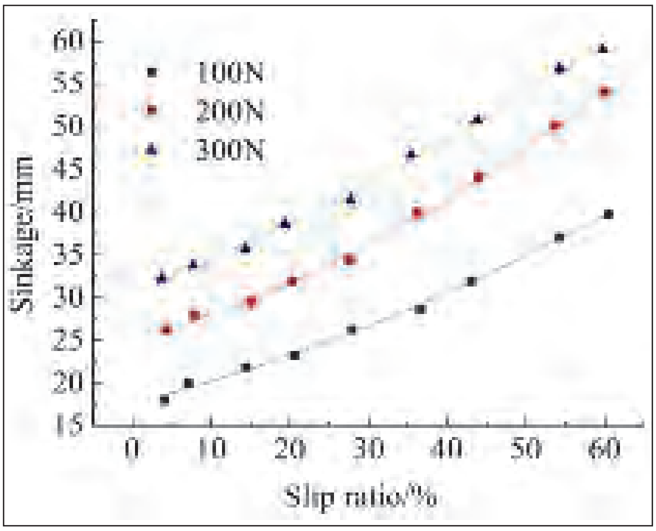
(d) The variable of motion resistance with slip ratio

Fig. 5: Influence of the velocity on the four parameters

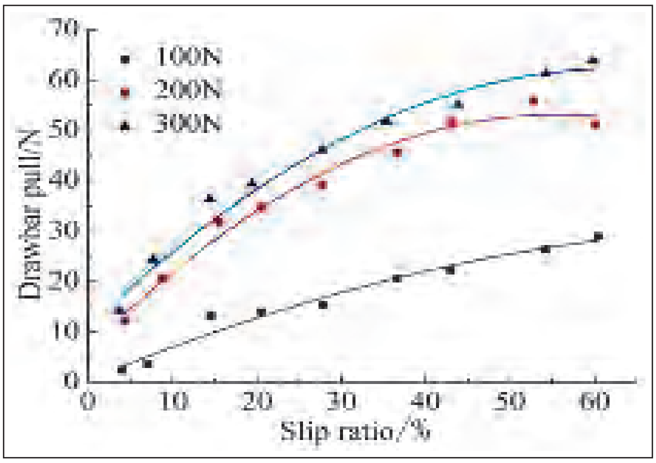
3.2. The effect of vertical loading on tractive performance.

Fig. 6 shows the influence of vertical load on the four parameters at the speed of 25mm/s. In Fig. 6(a), the curves show that the sinkage increases with the increasing of slip ratio, meanwhile, the sinkage increases with the increasing of vertical load. The maximum increase of sinkage under the load of 300N is greater by 32% than that under the load of 200N. The maximum increase of sinkage under the load of 200N is greater by 87% than that under the load of 100N. It is not understanding that the sinkage of the test wheel is heavily affected by the vertical load.

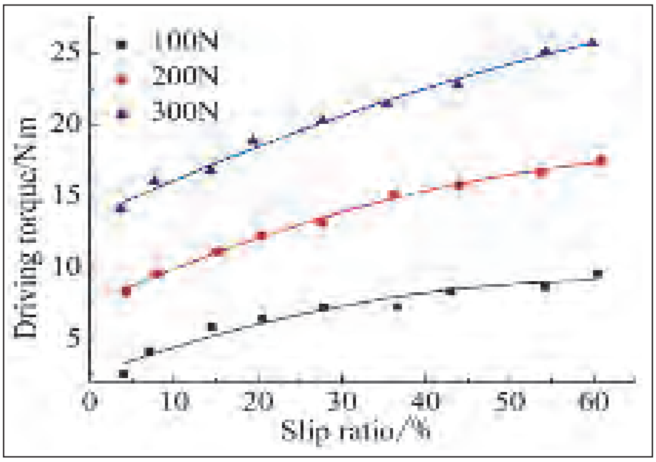
Fig. 6(b) shows that the drawbar pull increases with the increasing of slip ratio, meanwhile, drawbar pull increases with the increasing of vertical load.



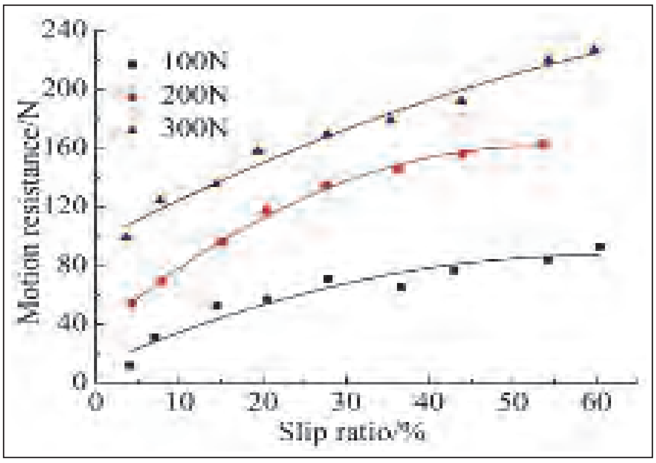
(a) The variation of singkage with slip ratio



(b) The variable of drawbar pull with slip ratio



(c) The variation of driving torque with slip ratio



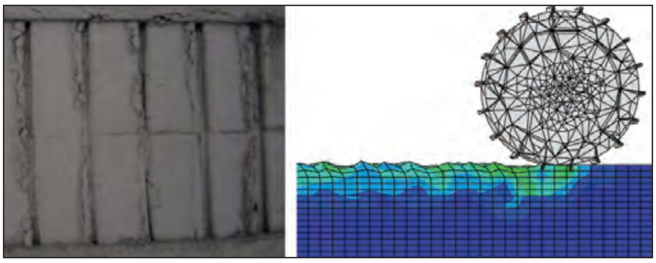
(d) The variable of motion resistance with slip ratio

Fig. 6: Influence of the vertical loading on the four parameters

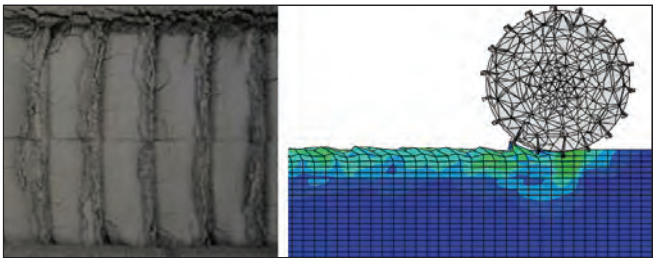
4. The analysis of FEA

Not all tractive test of lunar rover wheel can be conducted in soil bin, such as, the action between lunar rover wheel and lunar soil stimulant under the condition of low gravity, the actual deformation of lunar soil stimulant as the wheel moves etc. Therefore, the simulation of computer is indispensible for studying tractive performance of lunar rover wheel. FEA software Abaqus is good for solving the problems regarding non-linear aspect. Thus, ABAQUS can be considered to be applied for analyzing tractive performance of lunar rover wheel.

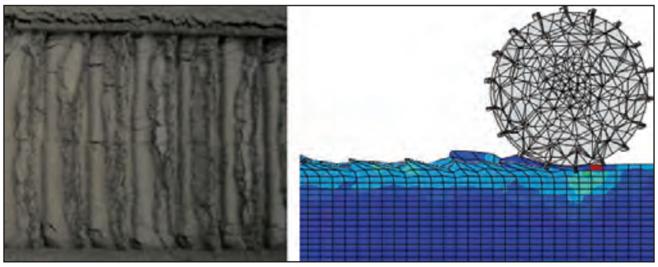
Fig. 7 shows comparative analysis between the rutting in the test and that in Abaqus. In the test and simulation, the wheel has velocity of 25mm/s, vertical load is 200N, and slip ratio is 15%, 25%, 40% respectively. It can be seen clearly in Fig.7 the disturbance of the rutting in simulat is heavier when slip ratio is higher. The result in simulation is similar with that in test. That means the Abaqus is good at simulating rutting.



(a) slip ratio is 15%



(b) slip ratio is 25%



(c) slip ratio is 40%

Fig. 7: Compare the rutting in the test with the rutting in FEA simulation

5. Conclusions

(1) Sinkage, drawbar pull, driving torque increase and motion resistance increases with the increasing of slip ratio.

(2) Sinkage, driving torque increase with the increasing of velocity. Drawbar pull decreases with the increasing of velocity. When slip ratio is below 18%, motion resistance increases with the increasing of velocity, and motion resistance decreases with the increasing of velocity when the slip ratio is greater than 18%.

(3) Sinkage, drawbar pull, driving torque increase and motion resistance increases with the increasing of vertical load.

(4) ABAQUS is good at simulating rutting.

References

1. Meirion-Griffith G, Spenko M. (2013): A pressure-sinkage model for small-diameterwheels on compactive, deformable terrain. *Journal of Terramechanics*, 50(1): 37-44.
2. Smith W, Melanz D, Senatore C, et al. (2014): Comparison of discrete element methodand traditional modeling methods for steady-state wheel-terrain interaction of small vehicles. *Journal of Terramechanics*, 56: 61-75.
3. Heverly M, Matthews J, Lin J, et al. (2013): Traverse performance characterization forthe mars science laboratory rover. *Journal of Field Robotics*, 30(6):835-846.
4. Meirion-Griffith G,Nie C, Spenko M. (2014): Development and experimental validationof an improved pressure-sinkage model for small-wheeled vehicles on dilative,deformable terrain. *Journal of Terramechanics*, 51(1): 19-29.
5. Gao H, Guo J, Ding L, et al. (2013): Longitudinal skid model for wheels of planetary exploration rovers based on terramechanics. *Journal of Terramechanics*, 50(5-6): 327-343.
6. Senatore C, Iagnemma K. (2013): Analysis of stress distributions under lightweight wheeled vehicles. J*ournal of Terramechanics*, 51(1): 1-17.
7. Creager C, Johnson K, Plant M, et al. (2015): Push–pull locomotion for vehicle extrication. *Journal of Terramechanics*, 57(1): 71-80.
8. Inotsume H, Sutoh M, Nagaoka K, et al. (2013): Modeling, analysis, and control of anactively recon Figurable planetary rover for traversing slopes covered with loose soil. *Journal of Field Robotics*, 30(6): 875-896.

DATA VALIDITY ANALYSIS AND HYBRID SOFT COMPUTING PREDICTION METHOD OF WATER RESOURCES IN MINING AREA

Continued from page 622

References

1. CAI Y. (2013): National water resources monitoring capacity building project and its progress, *Water Resources Informatization*, 20(6), 5-10.
2. Zhang F, Xue H-F, Xu D-S. (2013): Big data cleaning algorithms in cloud computing, *International Journal of Online Engineering*, 9(3),77-81.
3. Li X, Zhang L and Cao X et al. (2016): Retrieval of precipitable water vapor using MFRSR and comparison with other multisensors over the semi-arid area of northwest China, *Atmospheric Research*, 172(1),83-94.
4. Hajebi Saeed, Roshani Ehsan and Cardozo Nicolás et al. (2016): Water distribution network sectorisation using graph theory and many-objective optimization, *Journal of Hydroinformatics*, 18(1), 77-95.
5. Furong Yu and Wenxi Lu et al. (2012): Dynamic optimal control for groundwater optimization management with covariates, *Journal of Hydroinformatics*, 14(2), 386-394.
6. Zhao-Xing Li. (2014): A multi objective optimization algorithm for recommender system based on PSO, *Computer Modelling and New Technologies*, 18(7), 231-235.
7. Ausloos Marcel, Cerqueti Roy, Lupi Claudio. (2016): Long-range properties and data validity for hydrogeological time series: The case of the Paglia river, *Physica A: Statistical Mechanics and its Applications*, 470(1), 39-50.
8. Rahi, O.P. (2011): Optimization of hydro power plant design by Particle Swarm Optimization (PSO), *Procedia Engineering*, 30(1), 418-425.
9. James M T. (2013): Big data: Unleashing information, *Journal of Systems Science and Systems Engineering*, 22(2), 1-25.
10. Wen J, Zhou Z and Wang J et al.. (2013): A Sharp Condition for Exact Support Recovery with Orthogonal Matching Pursuit, *IEEE Transactions on Signal Processing*, 65(6), 1370-1382.