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EVALUATION OF THE MOBILITY PERFORMANCE WITH NUMERICAL ANALYSIS AND EXPERIMENTAL VALIDATION FOR A LUNAR EXPLORATION ROVER

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Abstract: To fulfill success of the space mission, the traversability of lunar/planetary exploration rover should be evaluated and fully understood with respect to the terrain properties. Meanwhile, wheel-soil interaction is extremely complicated, and thus numerical analysis is compared to experimental approach of mobility performance such as sinkage, drawbar pull. Also, the model of mobility performance is ultimately depends on experimentally determined terrain parameters. This paper describes two experimental methods used to identify the accurate terrain parameters in a lunar simulant. In addition, for the evaluation of mobility performance according to slip ratio and width of wheel in a lunar simulant, the wheel test bed of planetary exploration rover was assembled. Using the test bed, the preliminary experiments of the sinkage and drawbar pull according to variation of slip ratio and wheel width were carried out and evaluated. In addition, these experimental results were compared to the numerical analysis based on the wheel-terrain interaction model on lunar simulant.

Keywords: Terramechanics, Bevameter, Rover wheel test bed, Mobility performance

1. INTRODUCTION

Terramechanics is a study of the terrain properties between terrain and rover structures, and it has utilized for the purpose of design and performance evaluation such as agriculture machines, planetary exploration rover, etc[1-4]. The aim of terramechanics is to evaluate the mobility performance such as sinkage, drawbar pull in deformable terrain. In general, in order to predict the mobility performance of lunar exploration rover, wheel-terrain interaction model is used, and thus model uses the numerous formulas, such as classic Wong equation, Janosi-Hanamoto model, etc. It is ultimately depends on experimentally determined terrain parameters[4-7].

In this study, to identify the accurate terrain parameter in a lunar simulant, two experimental methods were described. From the experimental data, classic Wong equation and numerical analysis were utilized to derive the terrain parameters associated with normal and shear stress. Also, for the evaluation of mobility performance according to wheel width and slip ratio in lunar simulant, we constructed a test bed of rover wheel consists of the driving part of the rover wheel and sensing part of the various parameters[4,11]. Using the test bed, the effect of the sinkage and drawbar pull according to slip ratio and wheel width were carried out and evaluated. In addition, we compare with numerical analysis through experiment driving on lunar simulant.

2. WHEEL-TERRAIN INTERACTION MODEL

2.1 Pressure-sinkage relationship

Pressure-sinkage relationship plays an essential part in wheel-terrain interaction model. They are used to derive the normal pressure and sinkage formulas in lunar simulant, which are consequentially used to derive the mobility performance such as sinkage, drawbar pull, etc. Meanwhile, to describe the sinkage characteristics under a rectangular plate, Wong suggested pressure-sinkage relationship based on terramechanics[1].

Using this relationship, to determine the terrain parameter in lunar simulant, classic Wong method and numerical optimization are used to find the terrain parameters that minimize the individual cost functions[1,6].

2.2 Stress-shear displacement relationship

To predict the mobility performance, wheel-soil interaction model uses the stress-shear displacement relationship as well as pressure-sinkage relationship. The terrain parameters associated with shear stress are identified by Mohr-Coulomb failure criteria and Janosi-Hanamoto equation. According to the Mohr-Coulomb failure criteria, for given normal load, shear strength-normal stress relationship are represented by a straight line in the shear strength-normal stress plane. Also, to describe the shearing displacement in deformable terrain, Janosi and Hanamoto proposed the shear stress-shear displacement relationship.

To determine the terrain parameter associated with shear stress in lunar simulant, classic Wong method and numerical optimization are used to find the terrain parameter that minimize the cost function[6]. A cost function over each data point that is minimized to find the optimal terrain parameters regarding the shear stress[5].

2.3 Wheel-terrain interaction model

Wheel-terrain interaction can predict the physical phenomenon between wheel and terrain. The wheel-terrain interaction based on the work of Wong and Reece is used in this paper to model the interaction between wheel and terrain. As shown in Figure 1, the sinkage and drawbar pull can be calculated for wheel axis weight, radius, width, slip ratio, and terrain parameters[6]. However, validation of these predicted

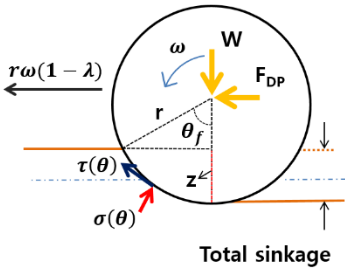


Figure 1: Wheel-terrain Interaction model.

values must be carried out through experimental approach. The detailed equations of wheel-terrain interaction and the simulation input parameters are presented in reference[7].

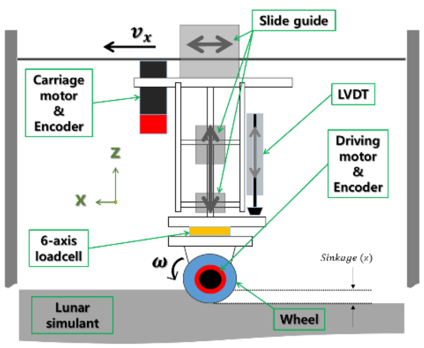
3. MEASUREMENT OF TERRAIN PARAMETERS

3.1 Normal stress parameter estimation

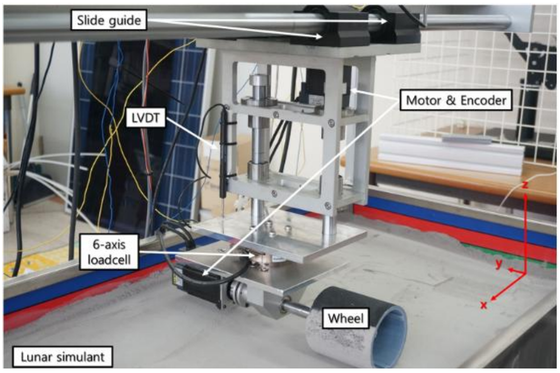
To obtain the terrain parameter of lunar simulant associated with normal stress, the pressure-sinkage test was conducted. From the experimental results, the each method was utilized to derive the terrain parameter of lunar simulant. The detailed configuration of bevameter and experimental results are summarized in reference[7].

3.2 Shear stress parameter estimation

The terrain parameters associated with shear stress are used the experimental data of Korea Institute of Civil Engineering and Building Technology[8]. From the experimental data, the classic Wong method and numerical optimization were utilized to derive the terrain parameters. The derived values of these parameters are described in reference[7].



(a) Schematic diagram



(b) Detailed view

Figure 2: CBNU rover wheel test bed.

4. DRIVING EXPERIMENT FOR VALIDATING WHEEL-SOIL INTERACTION MODEL

4.1 Test bed and experimental procedure

Figure 2 shows the test bed of rover wheel that was used to conduct the wheel-soil interaction model validation tests for experimentation according to variation of the slip ratio and wheel width. To maintain desired slip ratio for the driving part of the test bed, a closed-loop control system is configured with two motors and encoder. In order to measure precise sinkage values, LVDT was calibrated by voltage-distance relationship. Also, to obtain the steady state driving condition, the settle down data of the sinkage was achieved and used for the evaluation. In addition, 6-axis force and torque sensor is mounted on upper part of the wheel to measure the forces generated by the wheel driving. For the experimental verification according to various slip ratio and wheel width, experiments were carried out at slip ratio of 0.2, 0.4 and 0.7. Also, two types of wheel shape with different width were designed and prepared. In addition, the lunar simulant has similar mechanical and chemical properties with Moon terrain. So it was used for the experiment.

Figure 3 shows that the measured example regarding the desired slip ratio using the PID control on lunar simulant. From the figure, we can see that the desired slip ratio was achieved and maintained in stable. The transient change of the sinkage is shown in Figure 4 concerning the different slip ratio. To obtain the steady state driving condition, the settle down data of the sinkage was achieved and used for the evaluation of the mobility performance. The detailed configuration of test bed and the experimental procedure are summarized in reference[7].

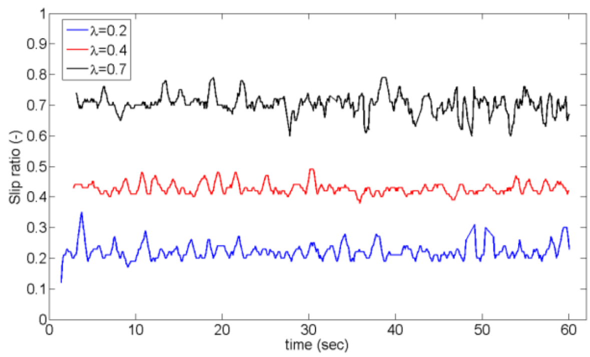


Figure 3: Measured example of slip ratio on lunar simulant.

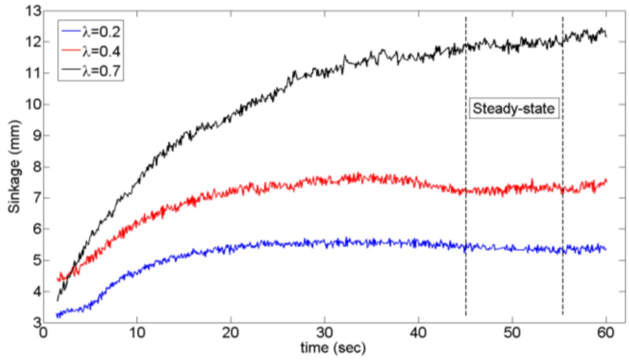


Figure 4: Measured example of sinkage on lunar simulant.

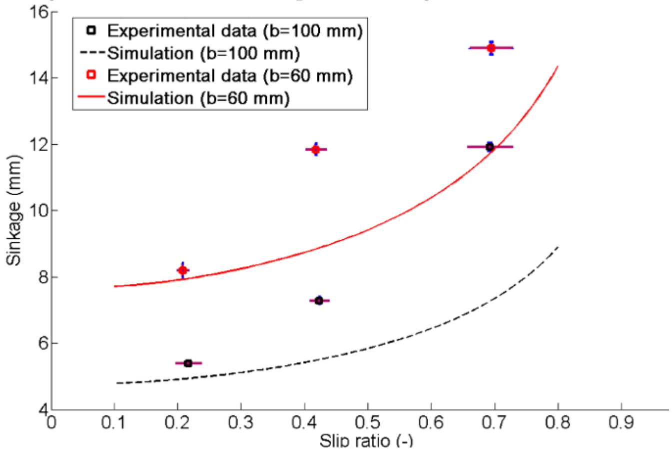


Figure 5: Experimental and simulation results in sinkage according to slip ratio and wheel width.

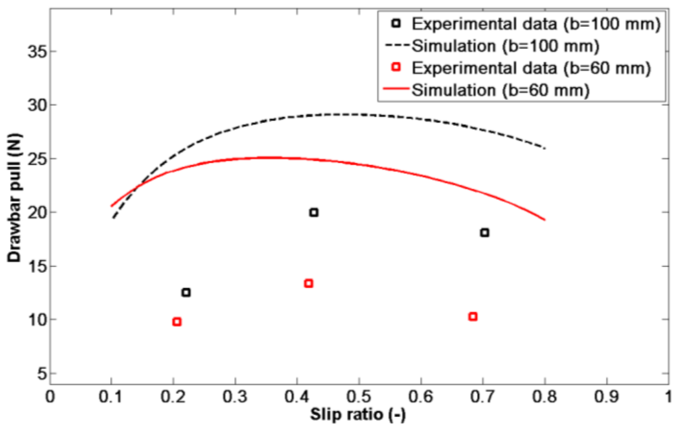


Figure 6: Experimental and simulation results in drawbar pull according to slip ratio and wheel width.

4.2 Experimental result

For validation of the wheel-terrain interaction model, the simulation results regarding the sinkage and drawbar pull are plotted against the experimental data in Figure 5-Figure 6[7]. As shown in Figure 5, the experimental results revealed that as increased slip ratio decreased wheel width in lunar simulant presents, values for sinkage gradually increase as well, and which shows the same trend estimated by simulation.

Figure 6 shows the measured and estimated drawbar pull. From the experimental results, wheel can't perform the optimal mobility performance at the initial stage from 0 to 0.2. So, the desired slip ratio for driving condition is from 0.3 to 0.4. Also, in the wheel-terrain interaction model, drawbar is bigger than that obtained by the wheel test bed experiment. The trend between the experimental results and estimated values are slightly similar, however the difference between the experimental results and simulation values are exist. One of the main reasons is that the wheel-terrain interaction model assumes the terrain properties as homogeneous rather than non-homogeneous terrain in the actual driving condition. In particular, for small and light-weight exploration rovers, this effect can play a significant role in the simulation[3,9]. It was concluded that there is still a need for betterment of wheel-terrain interaction model[7].

5. CONCLUSION

In this study, to determine the terrain parameters associated with normal and shear stress in lunar simulant, two experimental approaches were carried out. The individual terrain parameters were obtained from the experimental results by the each method. In addition, to evaluate the mobility performance according to various experimental conditions, the test bed was assembled. Using the test bed, the experimental approach to the evaluation of mobility performance regarding the sinkage and drawbar pull according to the slip ratio and wheel width was carried out and evaluated. In addition, these experimental results were compared to the numerical analysis based on the wheel-terrain interaction model on lunar simulant. Both experimental and simulation results represent to obtain the suitable driving condition that would improve the mobility performance on lunar simulant.

6. ACKNOWLEDGMENT

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