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月模擬砂を用いた走行試験場の開発と二輪小型ローバの走行性能検証

Development of a Driving Test Site Using Moon-Simulated Sand and Verification of Driving Performance of a Small Two-Wheeled Rover

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1. Introduction

In recent years, research on rovers capable of direct exploration of the lunar surface has attracted much attention. The regolith deposited on the lunar surface causes the wheels to slip and the rover gets stuck, a condition that renders it from driving. To prevent the small rover, which has a small ground contact area, weak ground compaction, and poor traveling performance, from getting stuck; it is necessary to establish a traveling system that can climb high slopes and to evaluate its traveling performance through hill climbing tests on soft ground. Previous studies have only verified hill climbing with silica sand, and even tests using moon-simulated sand have not been conducted at test sites where the angle can be changed to higher slope.

In this study, a traveling test site that can change the angle up to 30 degrees or more is constructed, and traveling tests of a small-sized rover are conducted in both silica sand and moon-simulated sand to clarify the effects of differences in soil environments on traveling performance.

2. Experimental procedure

2.1. Development of running test site

Figure. 1 shows the appearance and tilting mechanism of the moon-simulated sand running test site developed in this study. The running test site has an acrylic water case at 2000 mm long, 1000 mm wide, and 400 mm high fixed to the upper frame, and an electric lifting device mounted between the frames driving the case to achieve an arbitrary tilt angle. The soil was made of moon-simulated sand (FJS-1，Shimizu Corporation) spread to a depth of about 100 mm within the effective running surface of the acrylic case. The running test site using silica sand is shown in **Figure. 2**. This running test site is 1820 mm long, 450 mm wide, and 308 mm high. The soil was a 1 : 1 mixture of silica sand No. 5 and No. 6, spread to a depth of about 100 mm within the effective driving surface. Angle adjustments were made by lifting one side of the running test using a lift table.

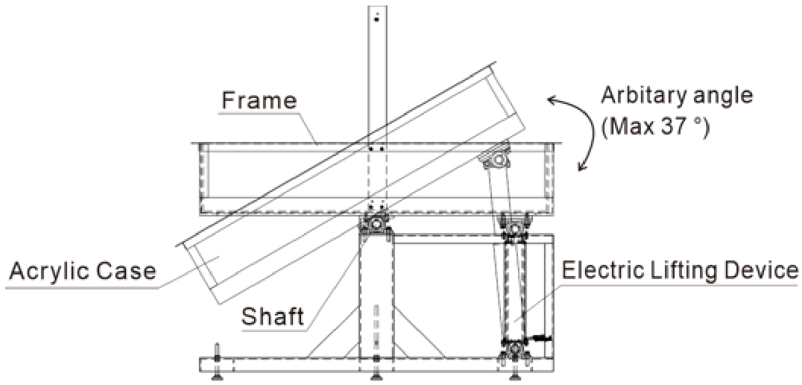


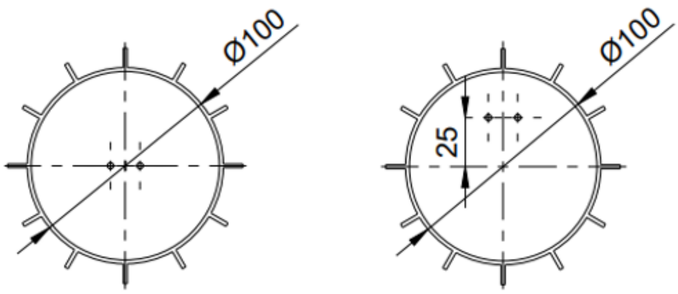
Figure 1. Driving test site using moon-simulated sand

Figure 2. Driving test site using silica sand

2.2. Fabrication of a small lunar rover

Figure. 3 shows the appearance of the rover fabricated in this study. Fusion360 was used to create drawings of the rover body and wheels, and a 3D printer (RAISE 3D) was used for laminated modeling. The rover is equipped with servo motors (XC330-M288-T, DYNAMIXEL) and Spresense (SONY) to rotate the wheels at an arbitrary angular speed. In this test, the left and right motors were driven at 10 rpm. The wheels of the rover are shown in **Figure. 4**. A cylindrical wheel with lugs and an eccentric wheel, in which the axle position of the cylindrical wheel is eccentric by 25 mm, were used. These wheel widths were set at 25 mm.

Figure 3. Appearance of Rover



(a) Cylinder (b) Eccentricity

Figure 4. Drawing of wheels

2.3. Running test

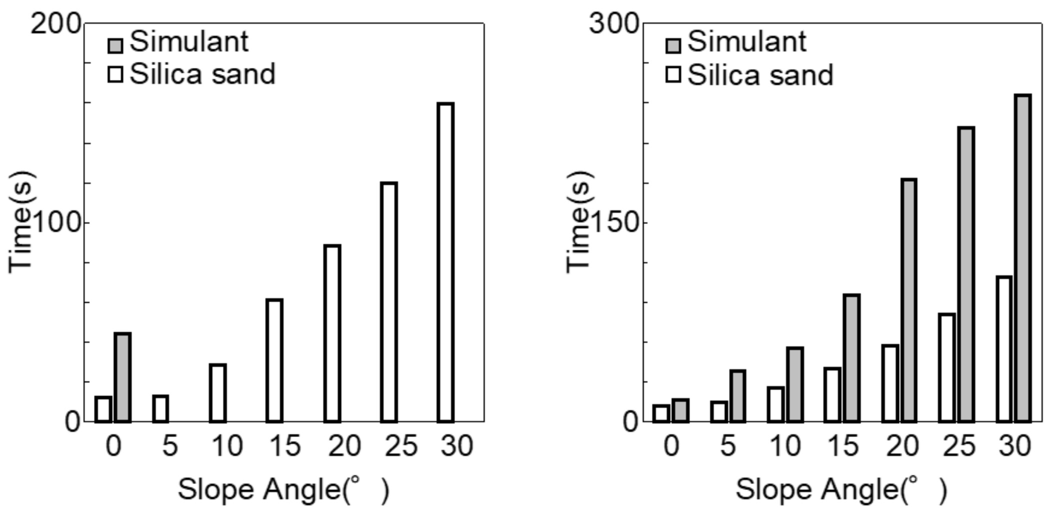
Running time and slip rate were used as indicators of the rover's running performance in this study. The slip rate was calculated using the following equation defined by the running distance L, wheel circumference length l_w, number of revolutions per unit time n, and running time t.

$$\lambda = \begin{cases} 1 - \dfrac{L}{l_w n t} : Driving(l_w n t \geq L) \\ 1 - \dfrac{l_w n t}{L} : Braking(L \geq l_w n t) \end{cases}, \quad (1)$$

The test was conducted with a travel distance of 700 mm and an inclination angle of 0 to 30 degrees in increments of 5 degrees. The soil was leveled over the driving range using a leveling machine, and a vane shear (FTD2CN-S, Nishinippon Tester) was used to confirm that the average shear torque at five points along the driving course was less than 0.5 ± 0.1 cNm for silica sand and 0.3 cNm for simulant, thus providing the initial conditions for driving tests.

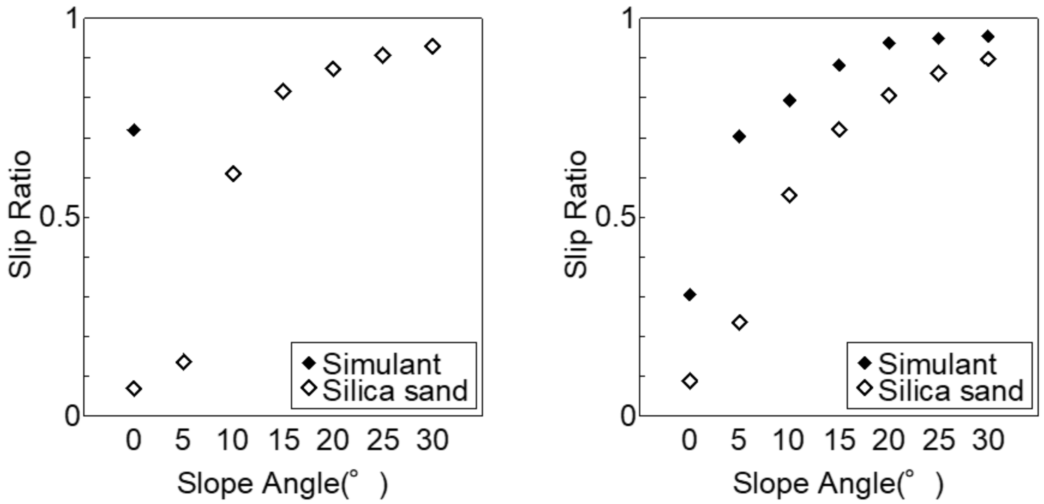
3. Results

Figure. 5 shows the results of running tests. The rover with the cylindrical wheel was able to climb up to 30 degrees on silica sand but was not able to climb at more than 5 degrees on moon-simulated sand. Although the rover with the eccentric wheel was able to climb hills up to 30 degrees even on moon-simulated sand, its running performance was significantly lower than that on silica sand.



(i) Cylinder (ii) Eccentricity

(a) Running time



(i) Cylinder (ii) Eccentricity

(b) Slip ratio

Figure 5. Results of running tests

4. Discussion

The moon-simulated sand used in this study (FJS-1) exhibits high dilatancy characteristics and is reported to be much more sensitive to density than silica sand. When traveling in a loosely packed section, the density of the moon-simulated sand changes from sparse to dense as the lugs scratch the soil to gain propulsive force. As the lug moves, the soil volume also changes, and the lugs are unable to acquire sufficient reaction force to move forward. When traveling on soft ground, the propulsive force received by the lugs of the rover contributes significantly to its traveling performance. Therefore, the lack of reaction force from the lugs may have accelerated the sinking of the rover, leading to a reduction in running performance.

5. Conclusion

A test site with a variable angle at a high slope was successfully developed, and a small rover was tested in both silica sand and moon-simulated sand. Due to the characteristics of the density change of the moon-simulated sand, the rover could no longer obtain propulsion from the lugs, and its running performance decreased. Eccentric wheels are also effective in moon-simulated sand.

References

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