ICRA'10 Planetary Rovers Workshop
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Traction Performance of Wheel and Track for Soft-Soil Traversal

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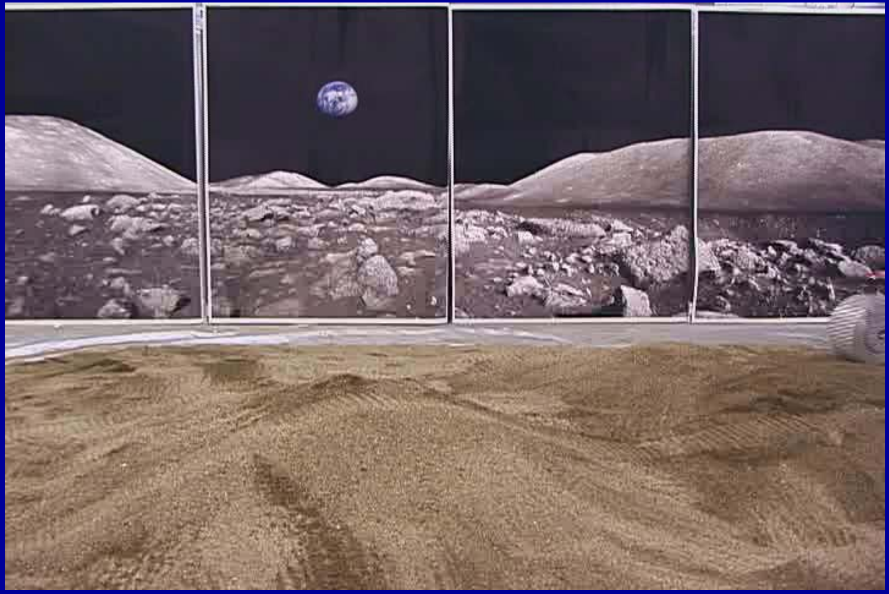
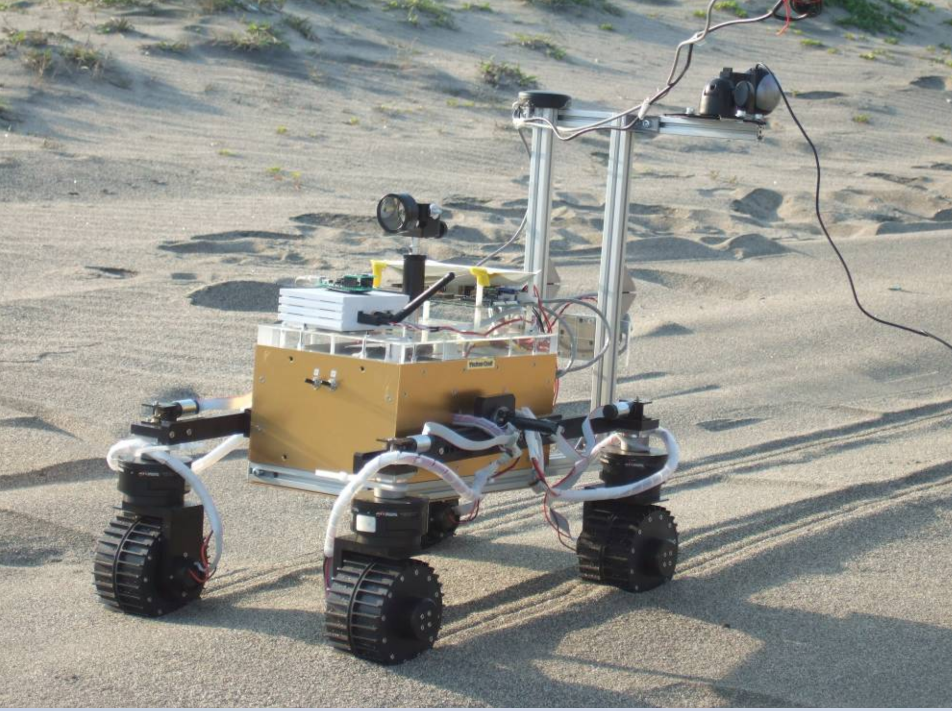
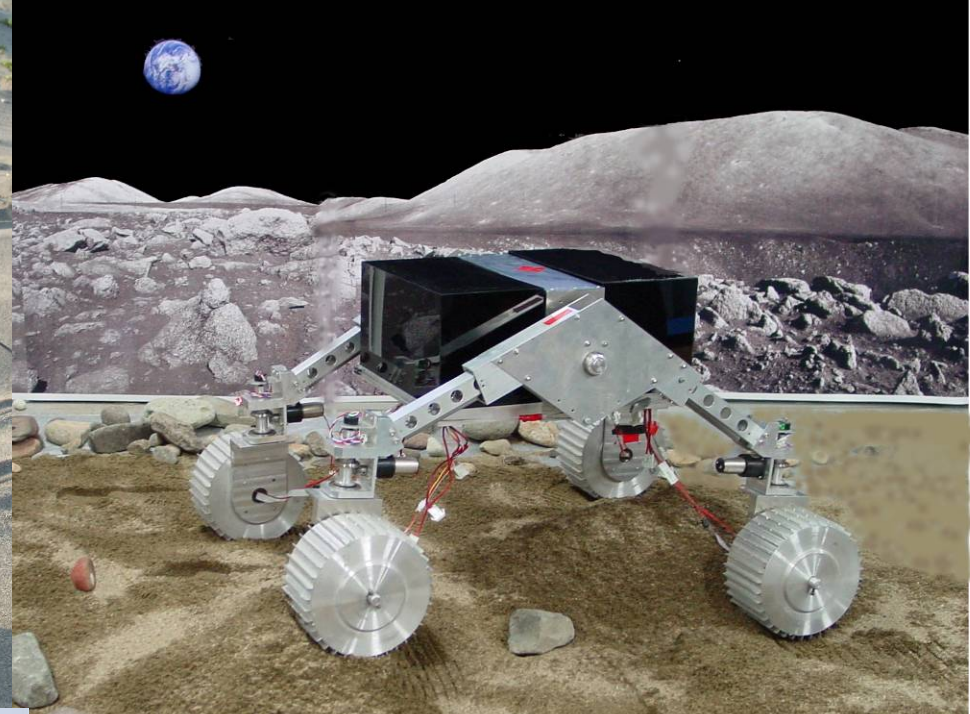
Traction Performance of Wheel and Track for Soft-Soil Traversal

- **Introduction**
- **Research Setup**
  - ***The Sand Box***
  - ***The Test Beds***
- **Traction Performance Evaluation**
  - ***Experimental Results for Wheel v.s. Track***
  - ***How can we improve the wheel traction?***
- **Summary**

Rover Test Beds in Tohoku Univ. *since 1997*



“Kaguya”
a Japanese Lunar Orbiter

- Launched on September 14, 2007.
- Orbiting 100km lunar polar orbit for global mapping and remote sensing of the Moon.


Apollo mission © NASA

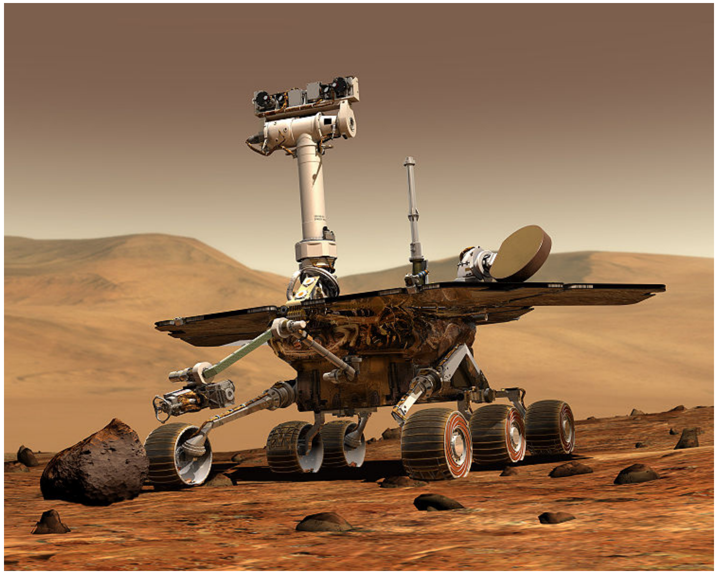
Lunar Rovers

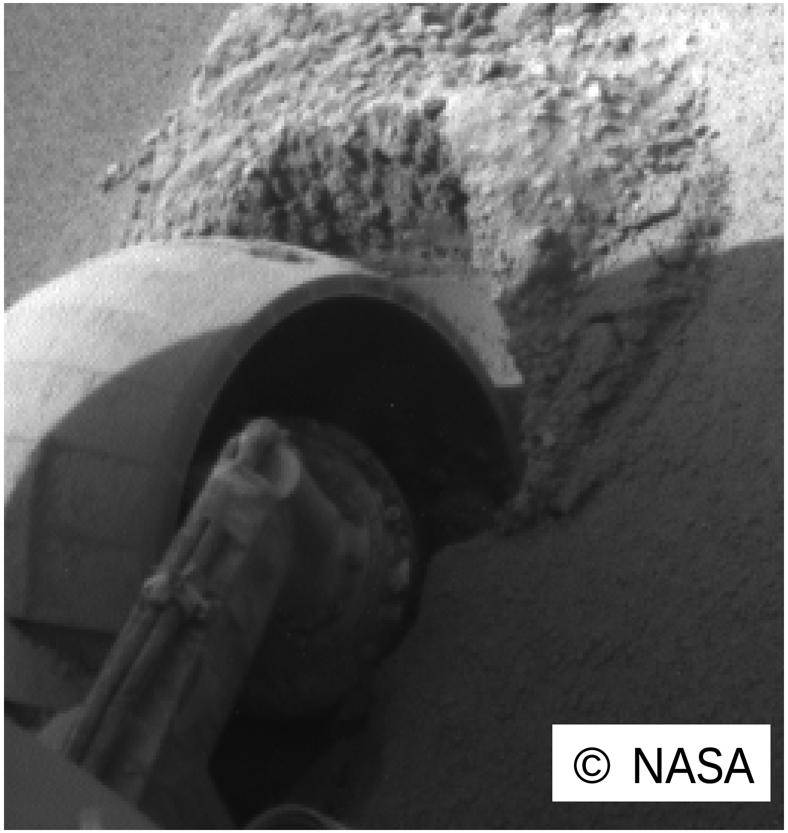
- Most of lunar surface is covered with soft soils (regolith).
- Wheel slippages/skids are unavoidable.
- Critical situations (immobility due to wheel spin, side slide, or tip over) should be avoided.
- Maximize the traction performance and power efficiency

Modeling and control based on substantial analysis of traction mechanics is important.

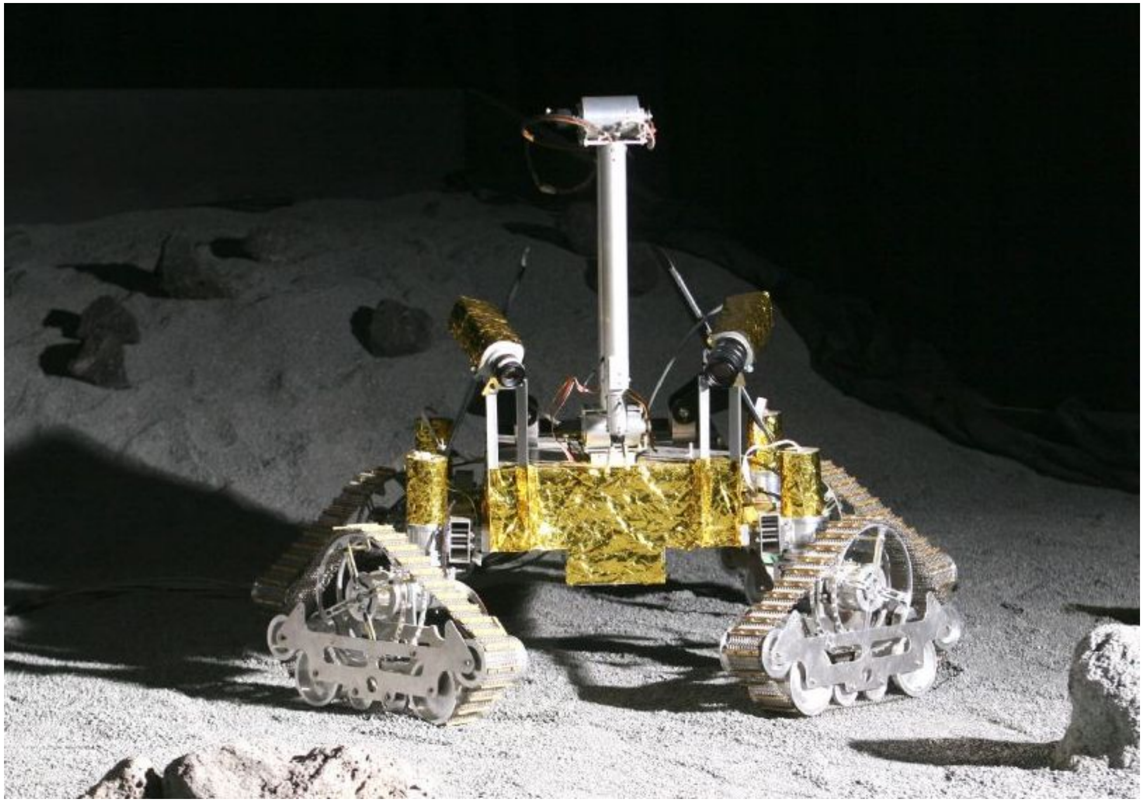
Wheeled rovers can be stuck in loose soil

NASA's Mars Exploration Rovers also experienced difficulty.





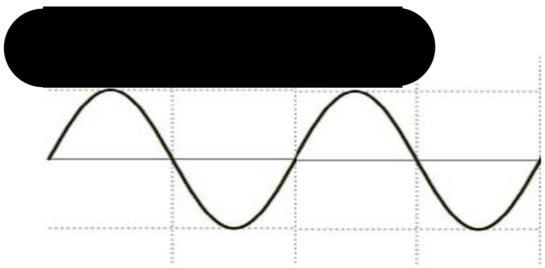
Do tracks work better than wheels?



Advantages of Tracked Vehicles:

- Higher slope-climbing capability
- Higher bump-crossing capability*

(*This is only true when the length of the track is larger than a "wave length" of the bumps.)



Disadvantages of Tracked Vehicles:

- Higher mass and higher energy consumption
- Higher complexity of mechanism
- Higher risk of track jamming or other mechanical failures

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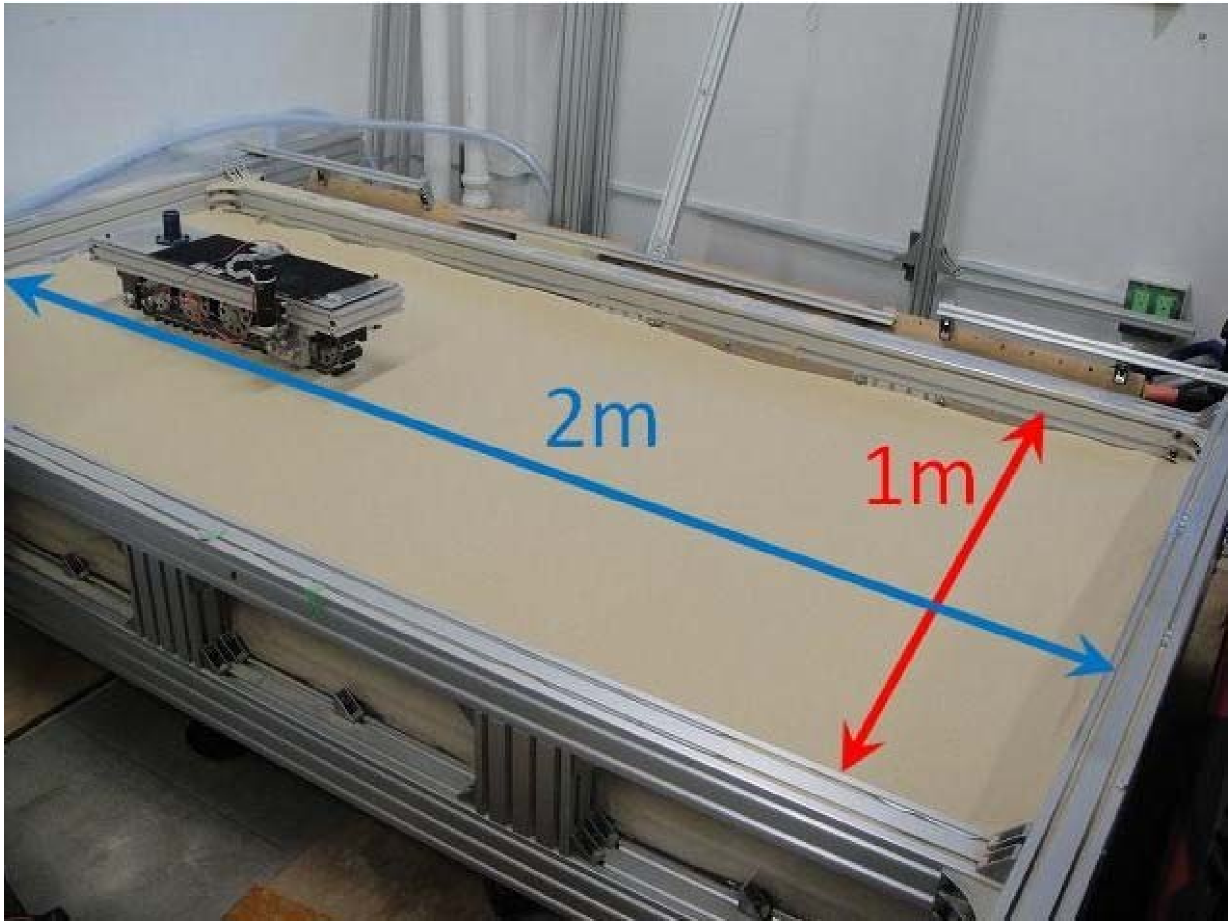
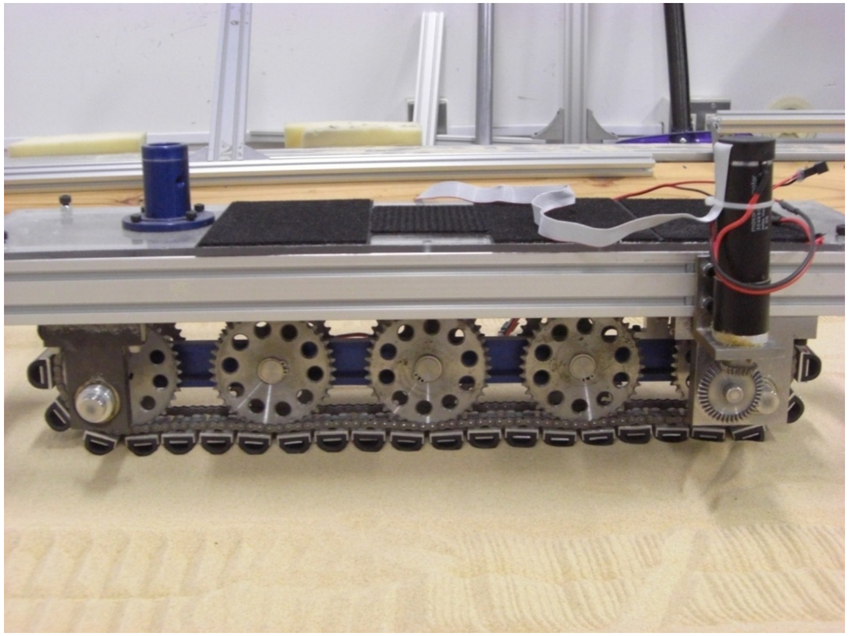
The Sand Box



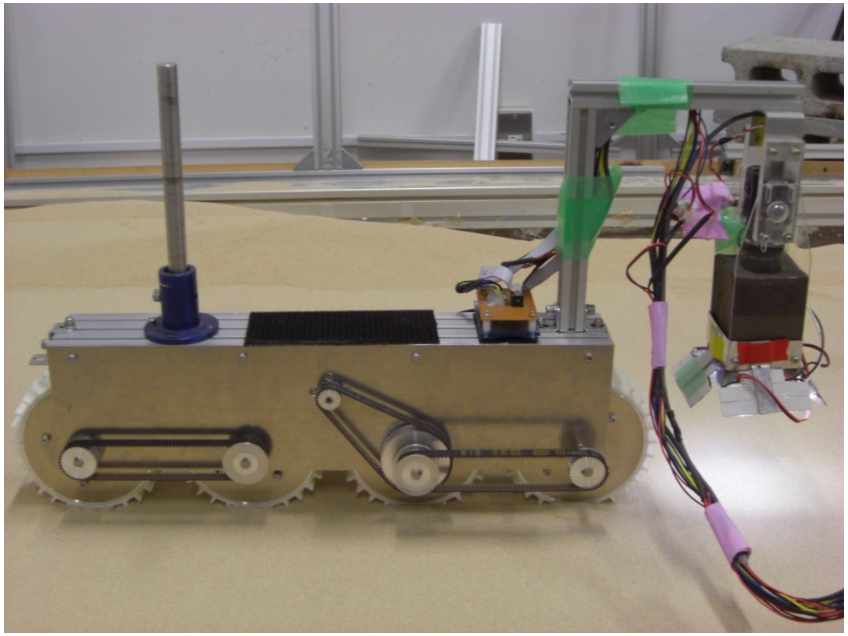
***Toyoura*-sand: a standard soil**
in Terramechanics research community

The Test Beds

Mono-Crawler



Inline Four-Wheels



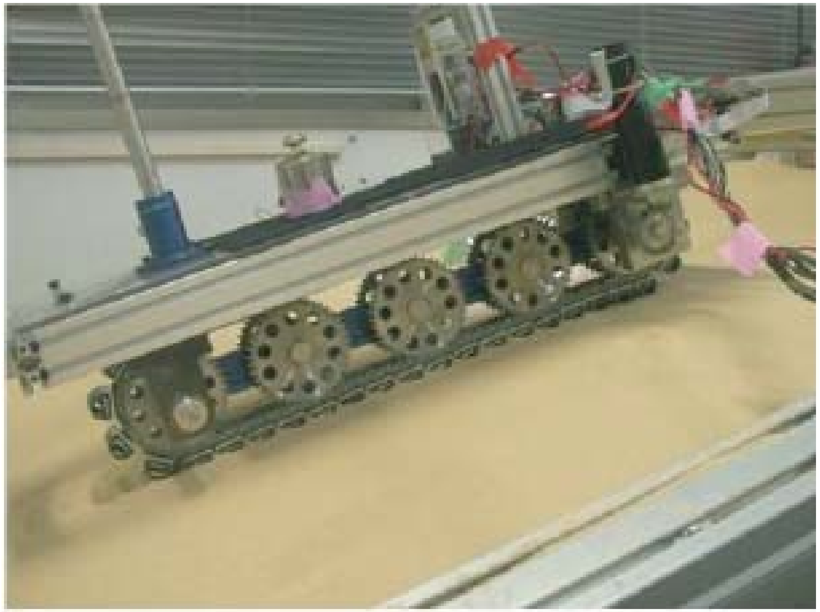
Length = 400 mm, Width = 40 mm, Weight = 6 - 18 kg

<u>for Crawler</u>: 375 - 1125 kg/m^2 (0.53 – 1.60 psi)

<u>for Wheels</u>: 1.5 - 4.5 kg/wheel

The Test Beds

Mono-Crawler



Inline Four-Wheels

Slope Angle: 0 – 16 degs (physically)

0 – 30 degs (equivalently)

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Performance Evaluation

Slip Ratio

$$s = \frac{v_d - v}{v_d} = 1 - \frac{v}{v_d}$$

v_d : circumference velocity of crawler belt or wheel

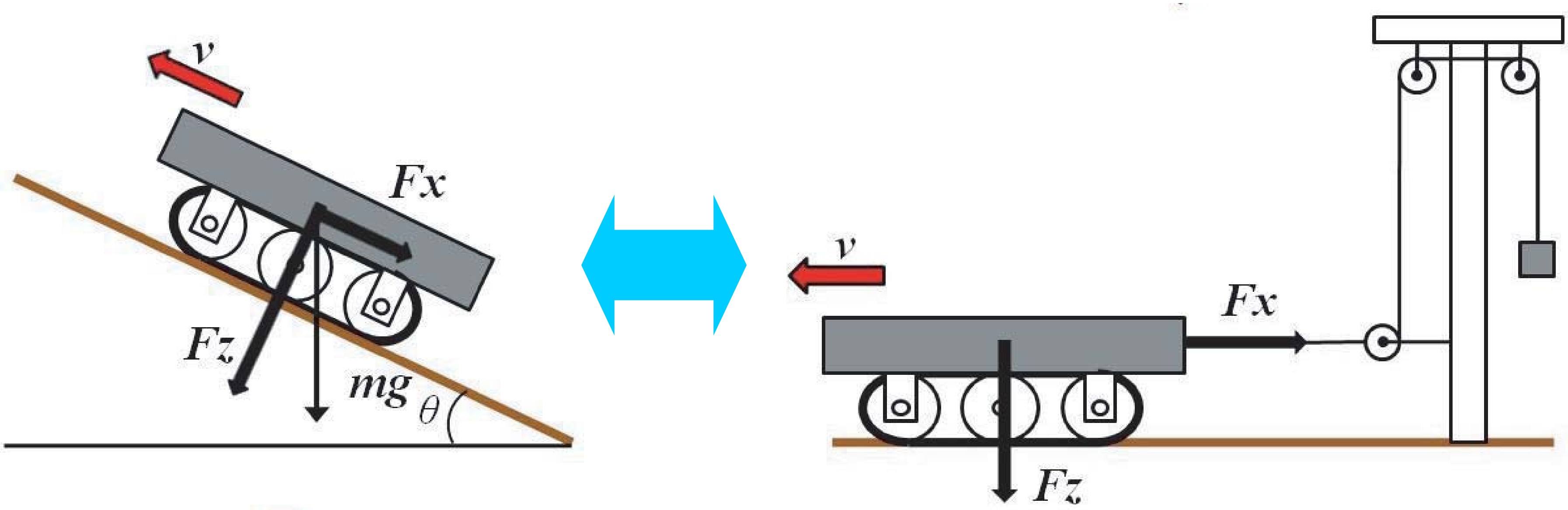
v : body velocity of the test bed

Drawbar Pull (DP)

DP = Traction Force - Resistance

Slip Ratio ー Drawbar Pull
Slip Ratio ー Slope Angle

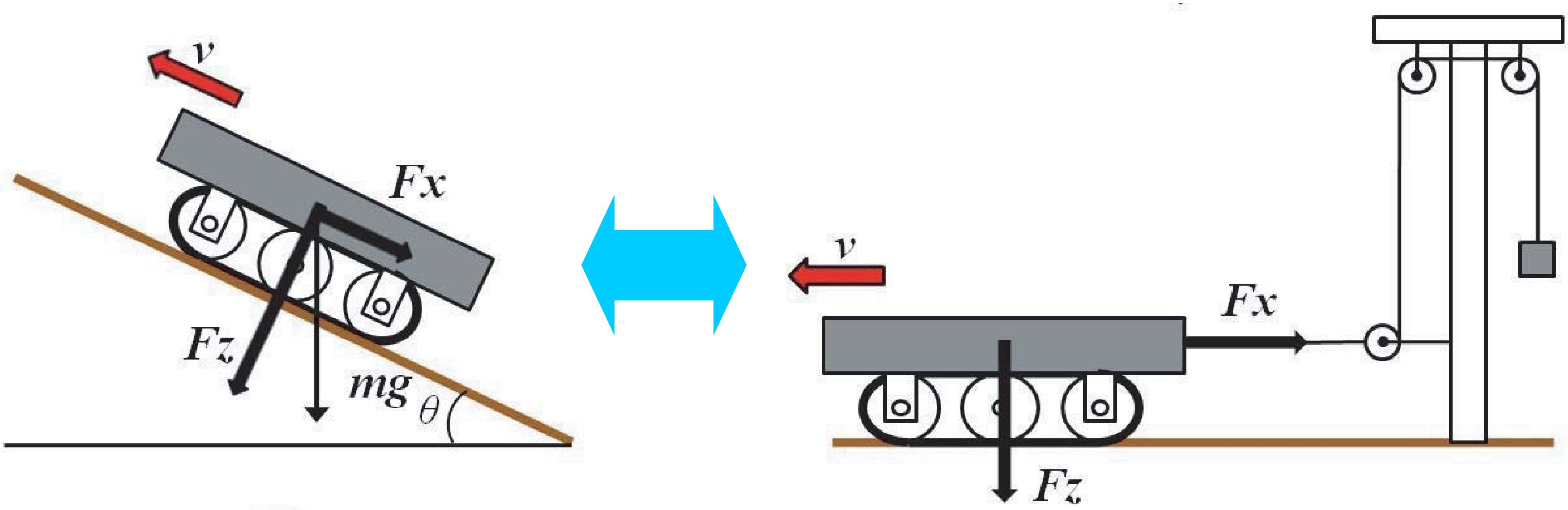
Q: Is the slope climbing condition equivalently tested by the increased horizontal load?



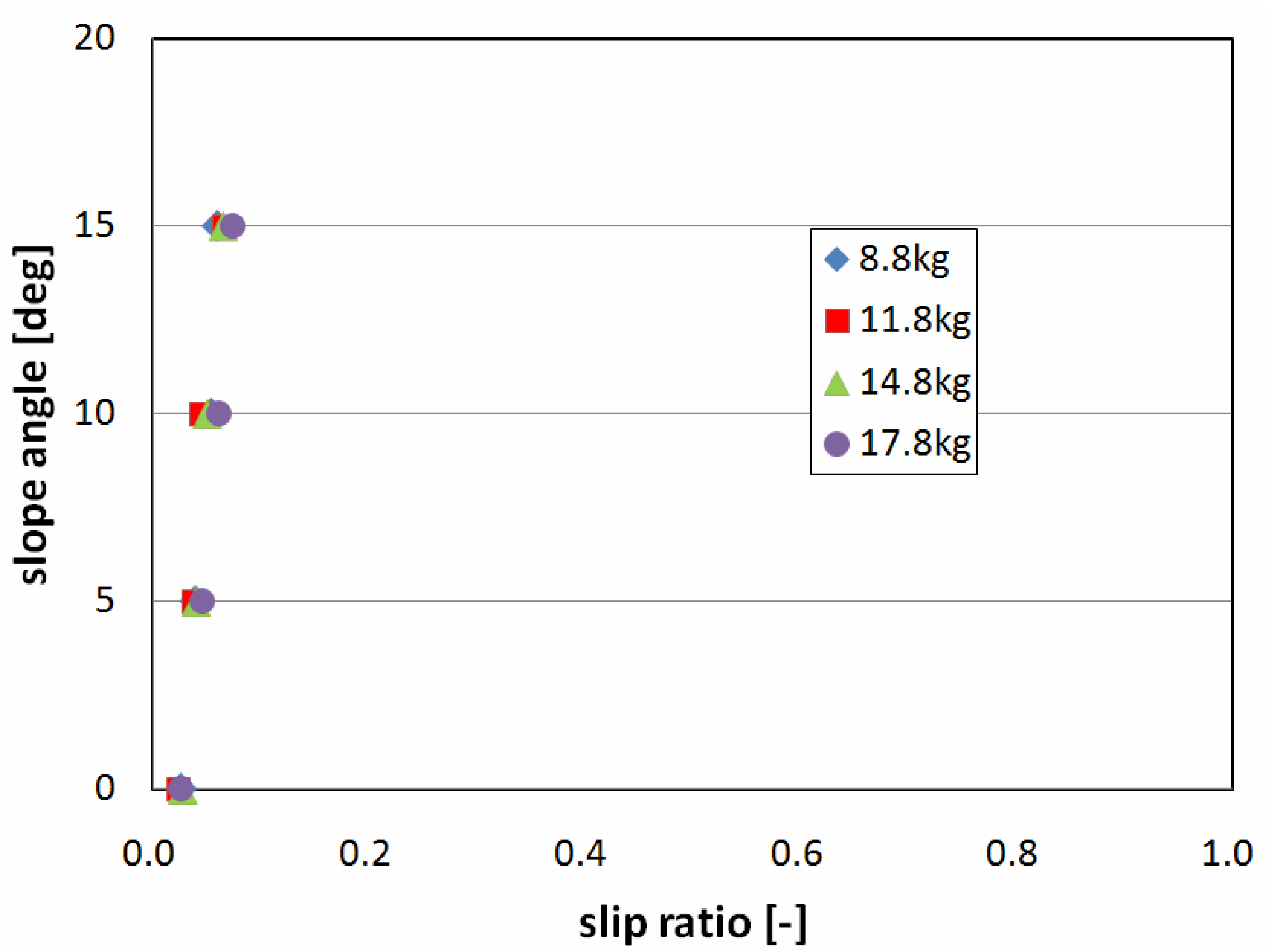
$$\theta = \tan^{-1}\frac{F_x}{F_z}$$

Q: Is the slope climbing condition equivalently tested by the increased horizontal load?

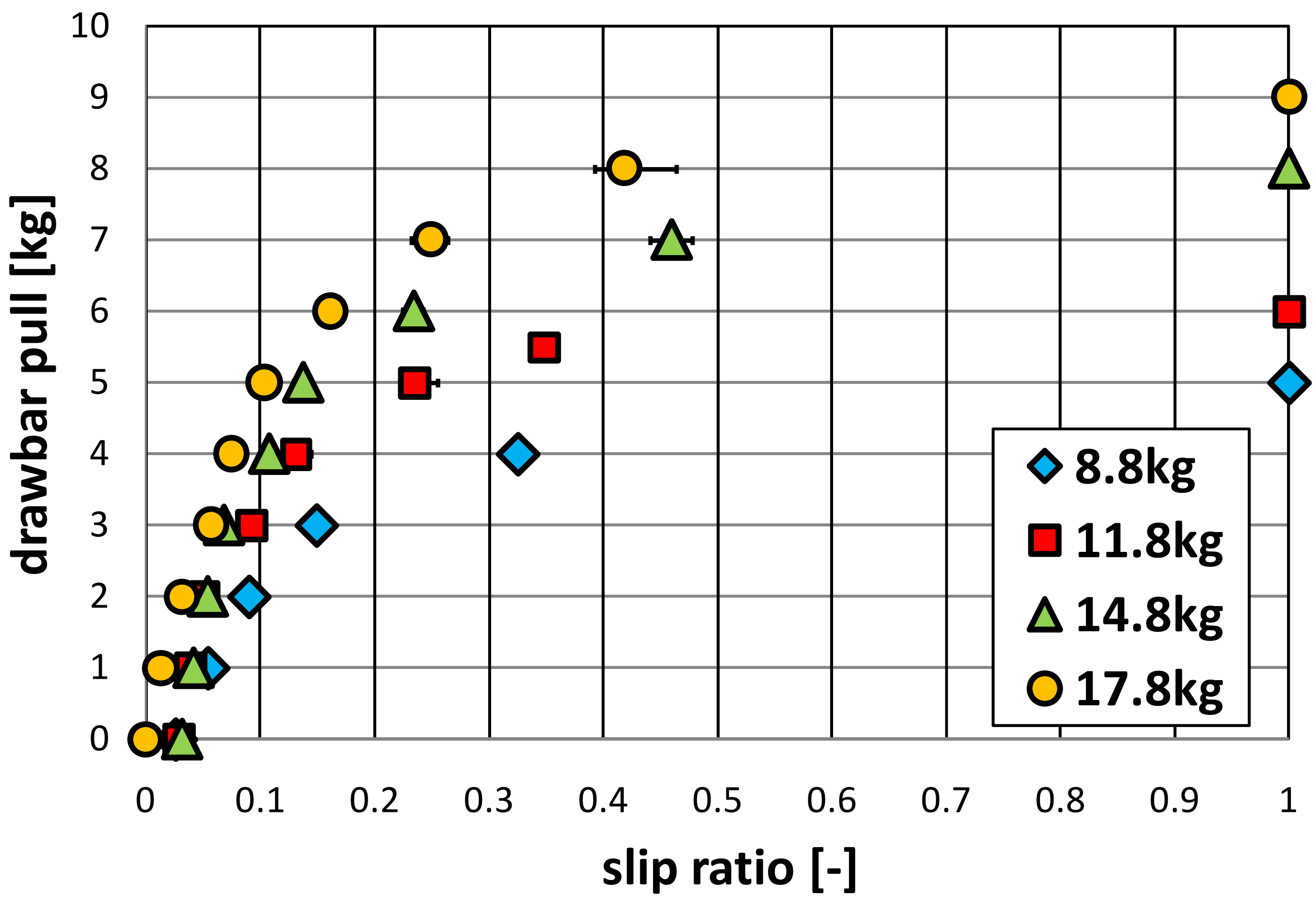
A: Yes, that seems true as long as no landslide (avalanche) occurs.



Experimental Result 0 (track)

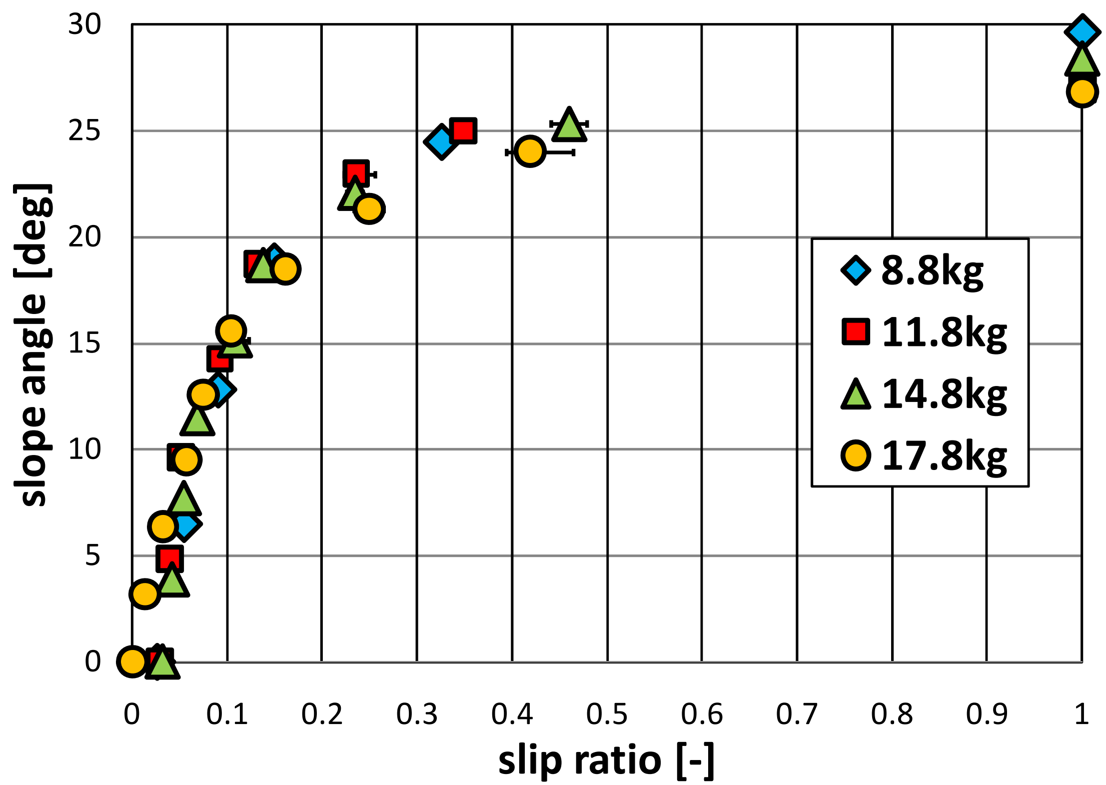


Experimental Result 1a (track)



The Drawbar Pull increases along with the vertical load Fz.

Experimental Result 2a (track)

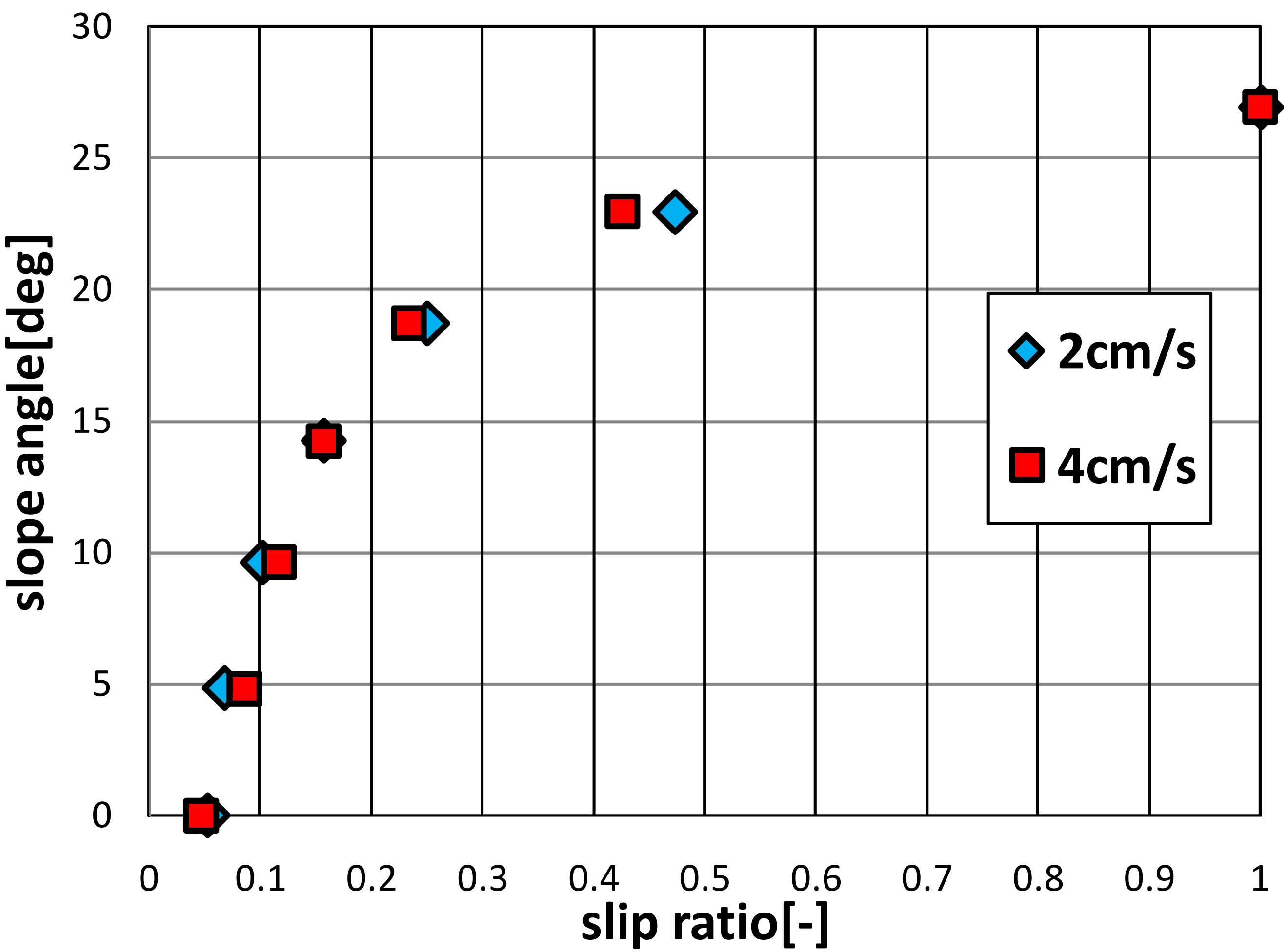


But the ratio of DP/Fz (= slope angle) is not affected by Fz.

This fact suggests that the traction force Fx is in proportion to the vertical load Fz (like *friction*), and the resistance R is relatively small.

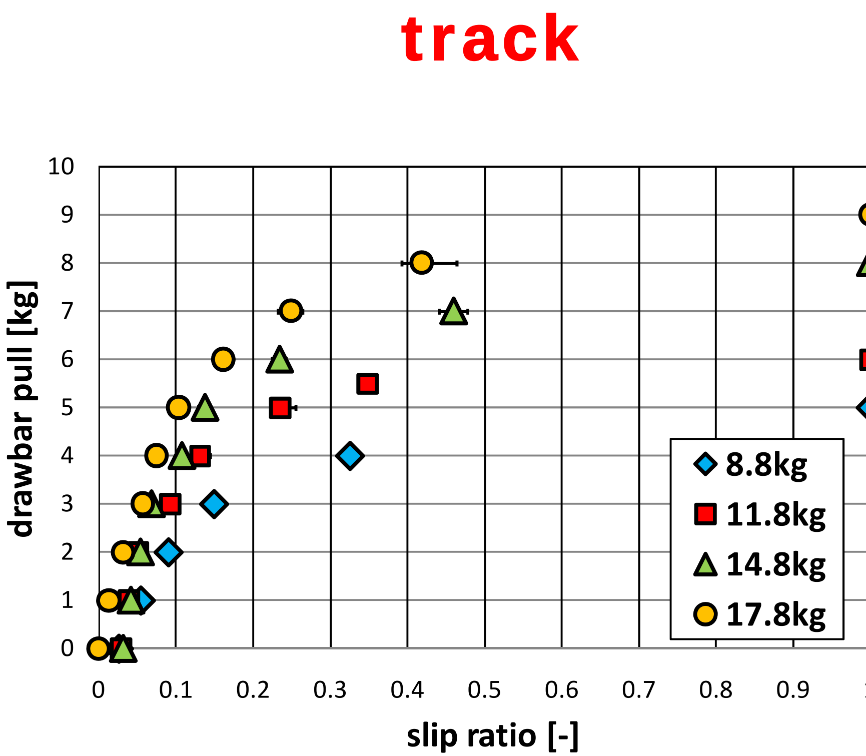
$$DP/Fz = Fx/Fz - R$$

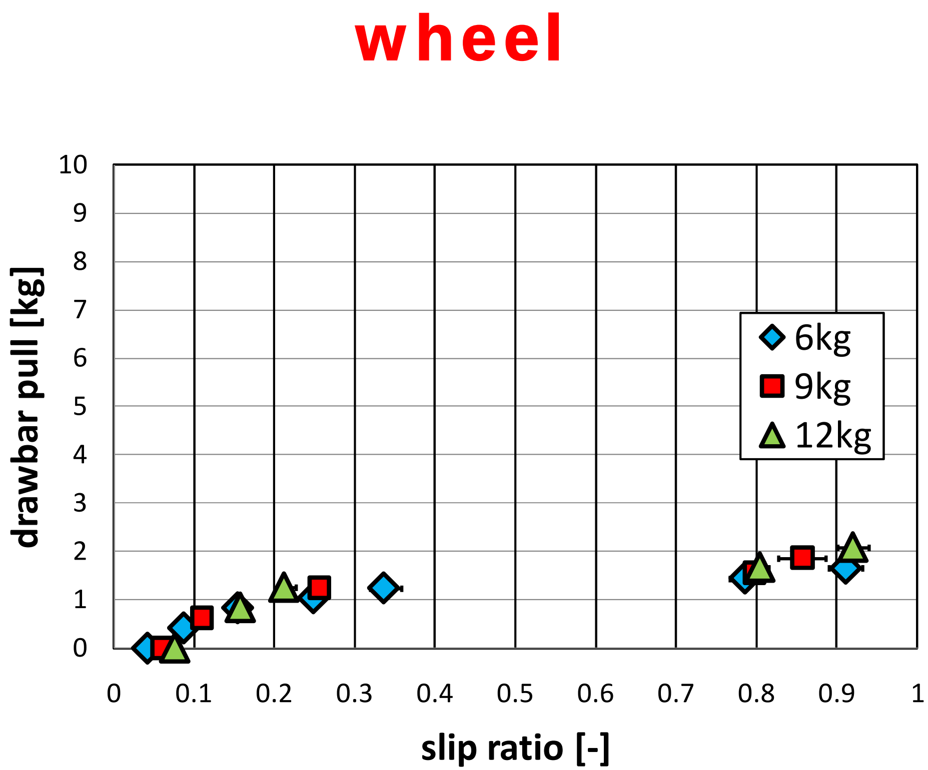
Experimental Result 3a (track)



Velocity dependency is not observed between 2 and 4 cm/s.

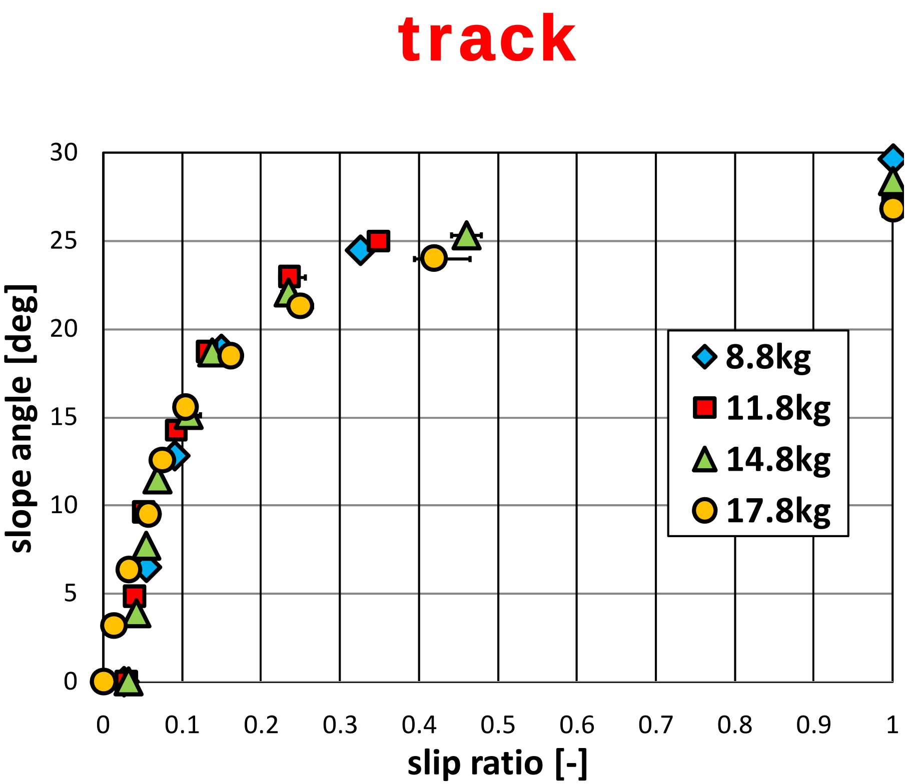
Experimental Result 1b (wheel)

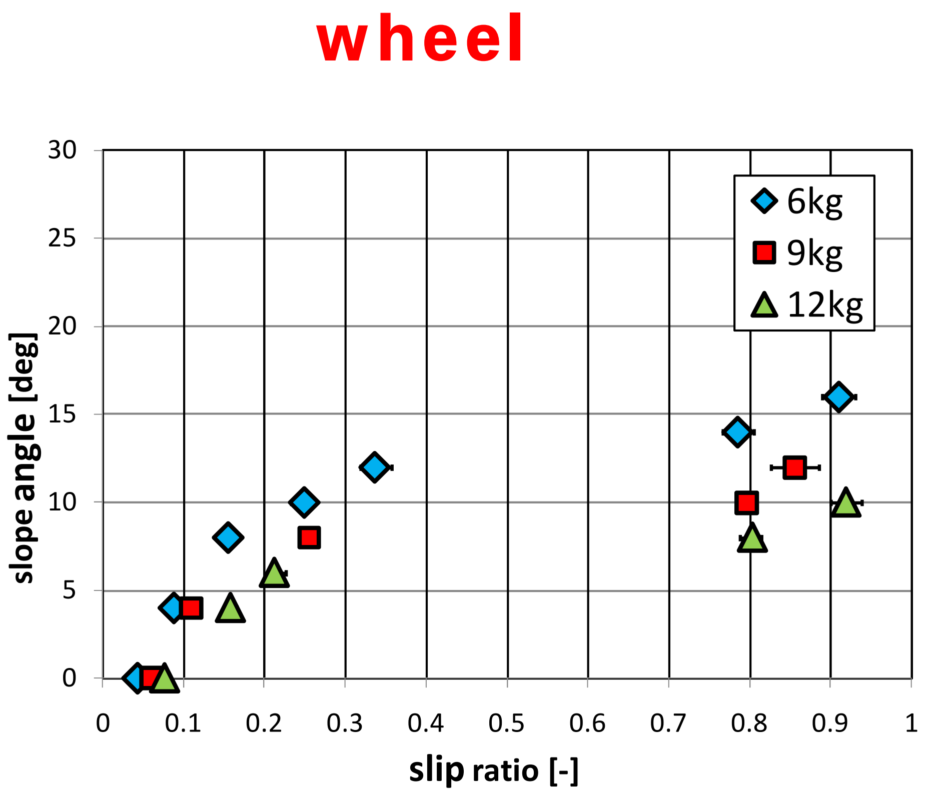




Drawbar Pull v.s. Slip Ratio

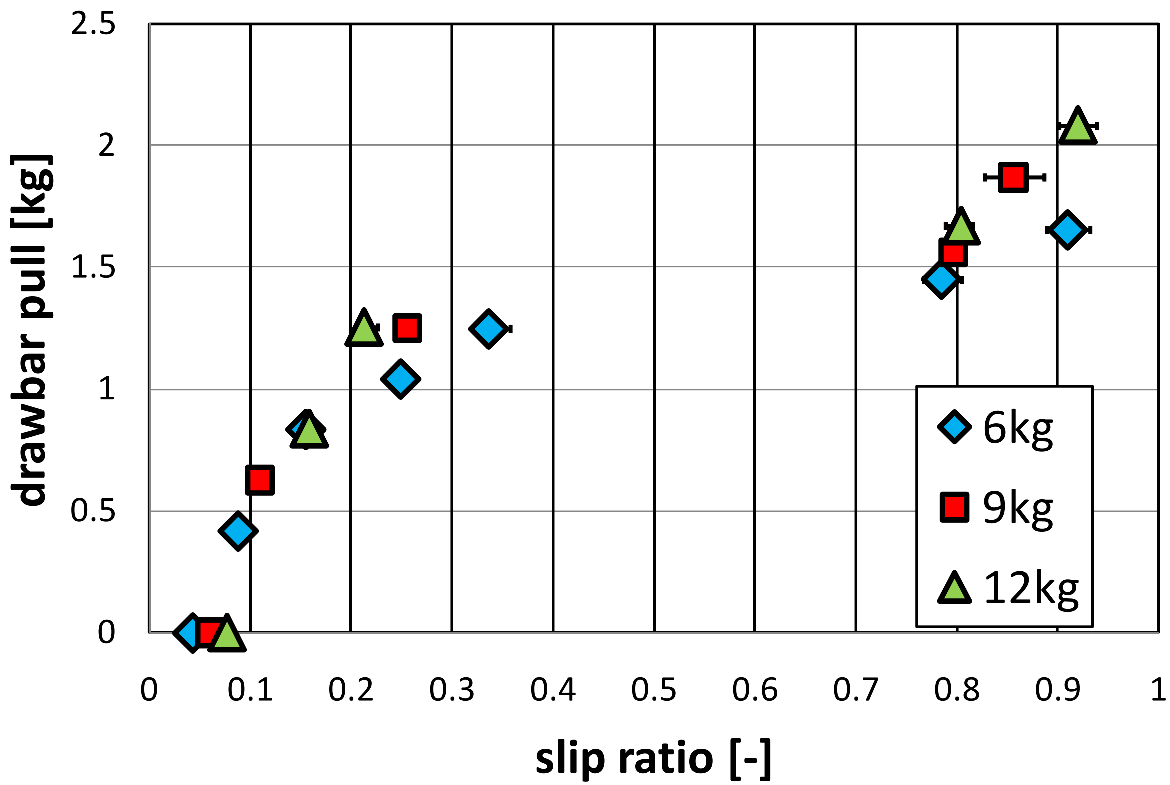
Experimental Result 2b (wheel)





Slope Angle v.s. Slip Ratio

Experimental Result 1b (wheel)

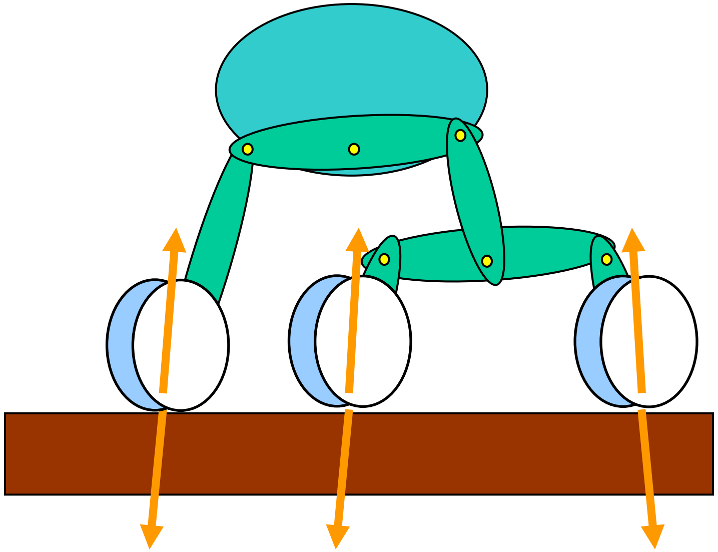


In wheel, DP is not much affected by Fz.

This fact suggests that the wheel traction is NOT like *friction*, because of relatively large the resistance R due to wheel sinkage.

$$DP/Fz = Fx/Fz - R$$

Traction Model for a Rigid Tire on Soft Soil



(Bekker 1956, Wong 1978)

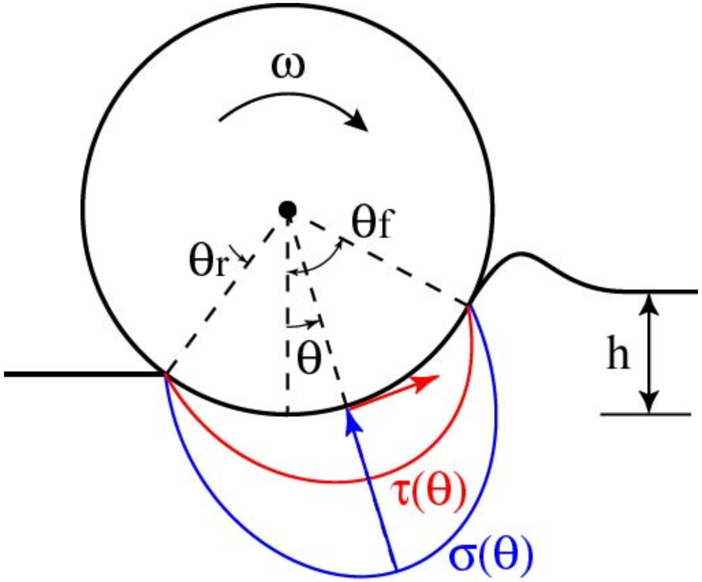
$$W = rb\int_{\theta_r}^{\theta_f} \{\sigma(\theta)\cos\theta + \tau(\theta)\sin\theta\}d\theta$$

$$DP = rb\int_{\theta_r}^{\theta_f} \{\tau(\theta)\cos\theta - \sigma(\theta)\sin\theta\}d\theta$$

$$T = r^2 b\int_{\theta_r}^{\theta_f} \tau(\theta)d\theta$$

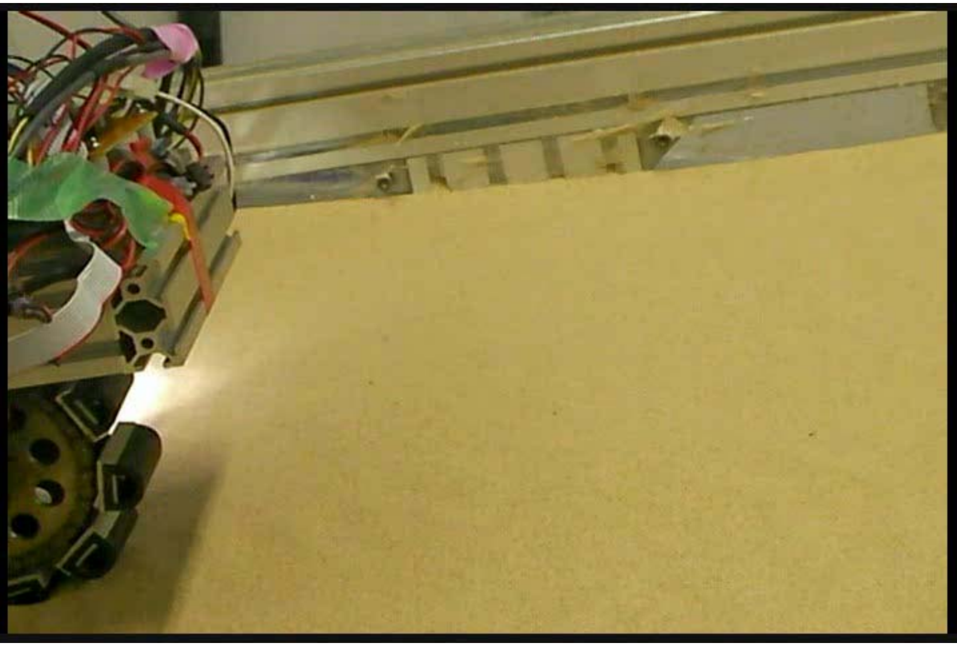
$$\tau(\theta) = (c + \sigma\tan\varphi)\left(1 - e^{a(s)}\right)$$

$$a(s) = -\frac{r}{k}\left[\theta_f - \theta - (1-s)(\sin\theta_f - \sin\theta)\right]$$

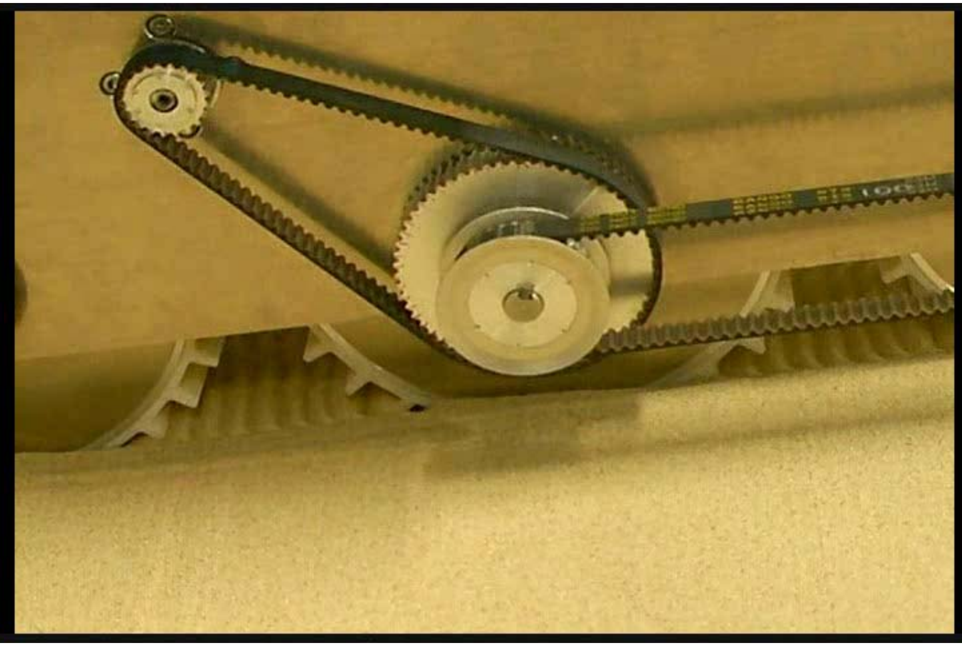


Comparison of Track and Wheel

Weight = 9kg , slope angle = 10°

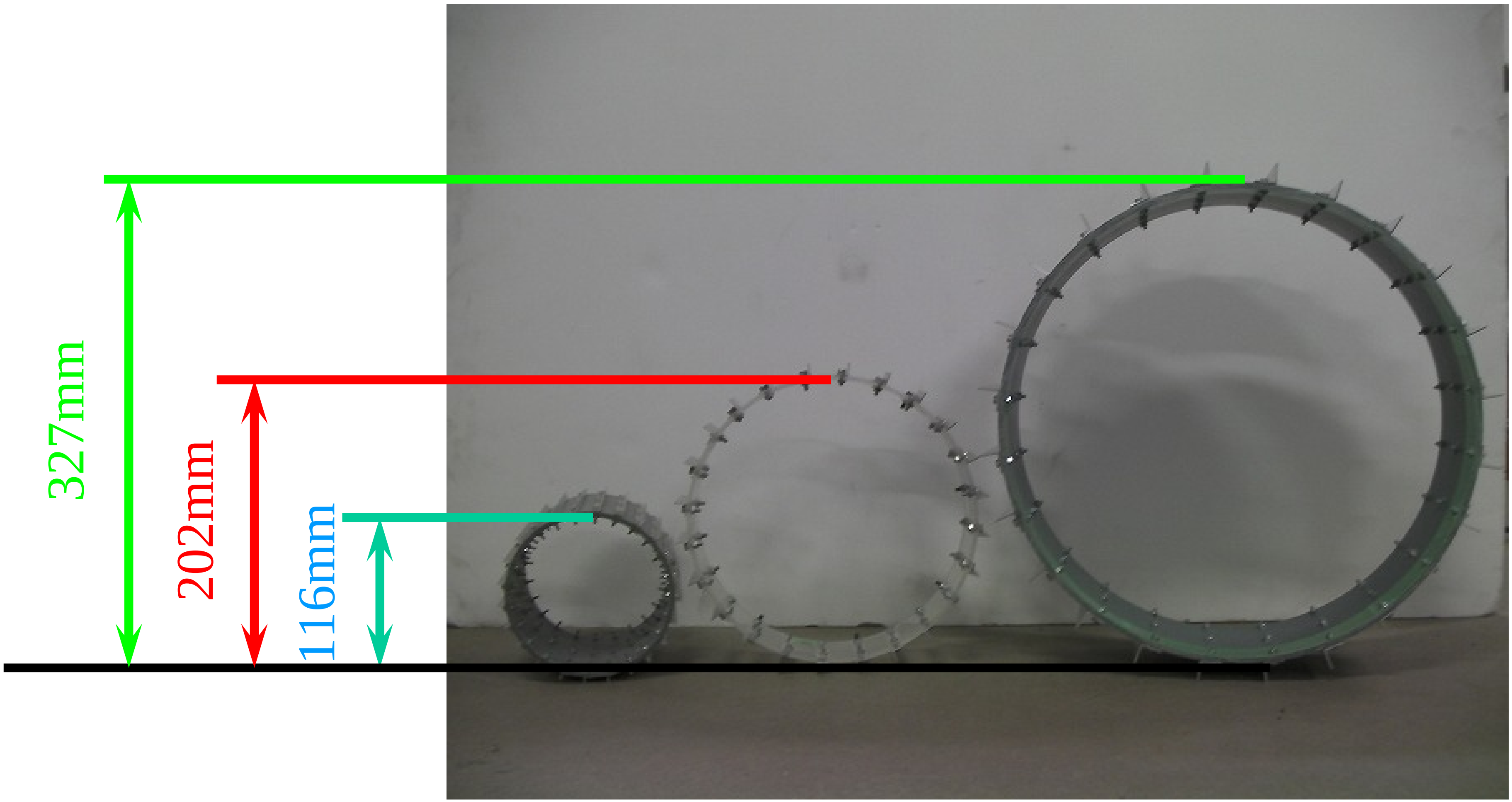


Slip Ratio = 0.054



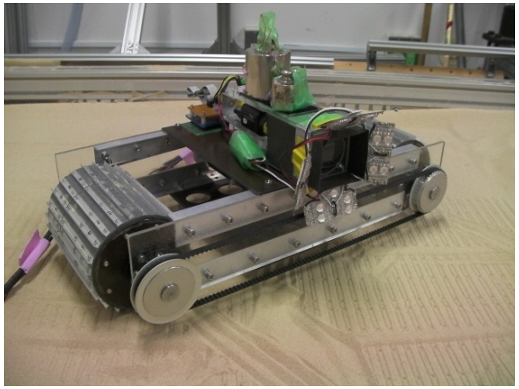
Slip Ratio = 0.774

Q: How can we improve the traction performance of the wheels?

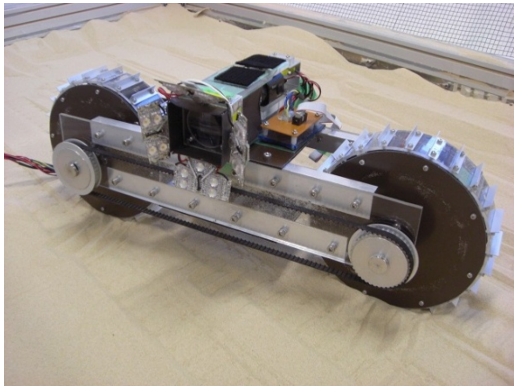


Wheels with Different Dimensions

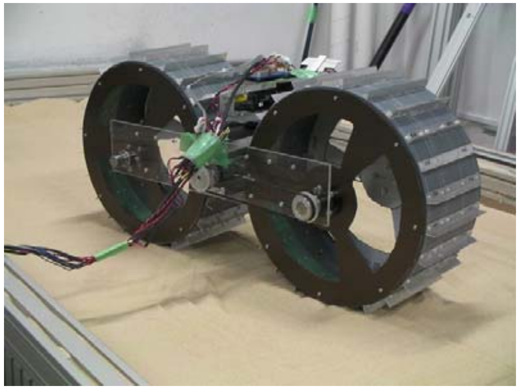
	D=100mm	D=200	D=300
diameter [mm]	116	202	327
lug height [mm]	5	9	15
number of lugs	24	24	24
width [mm]	50, 100, 150	50, 100, 150	50, 100, 150



D=100

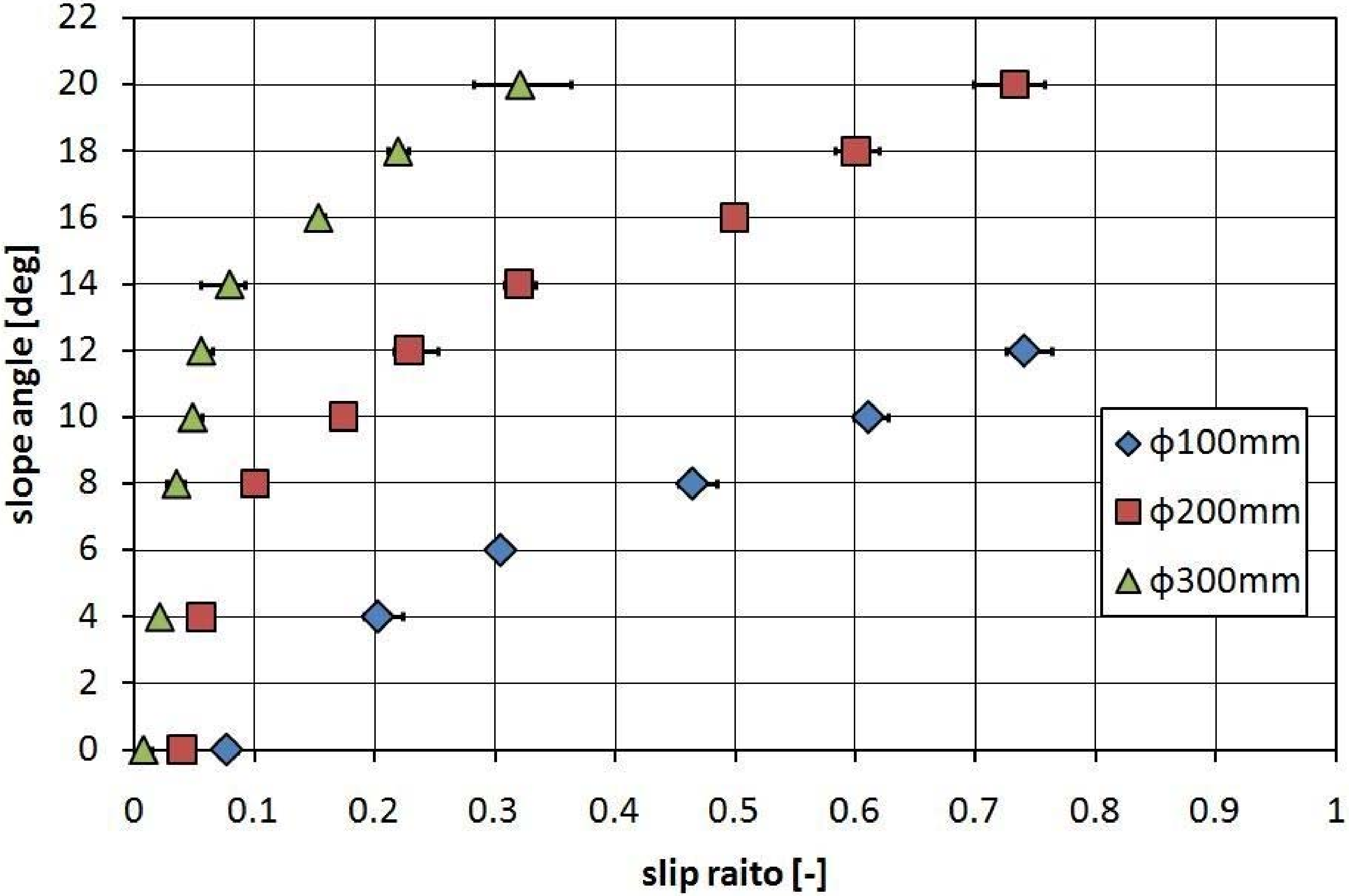


D=200



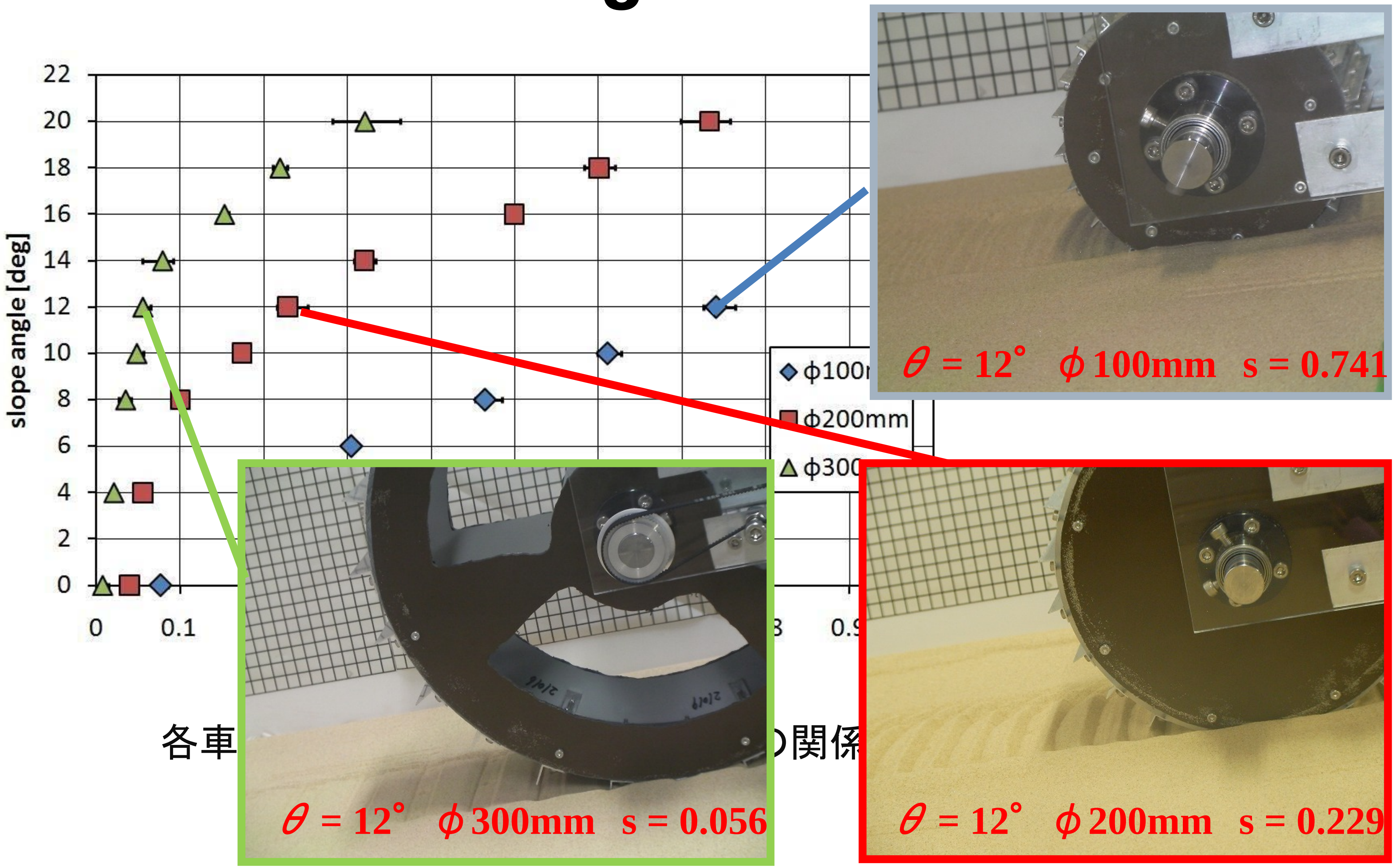
D=300

With Larger Diameter

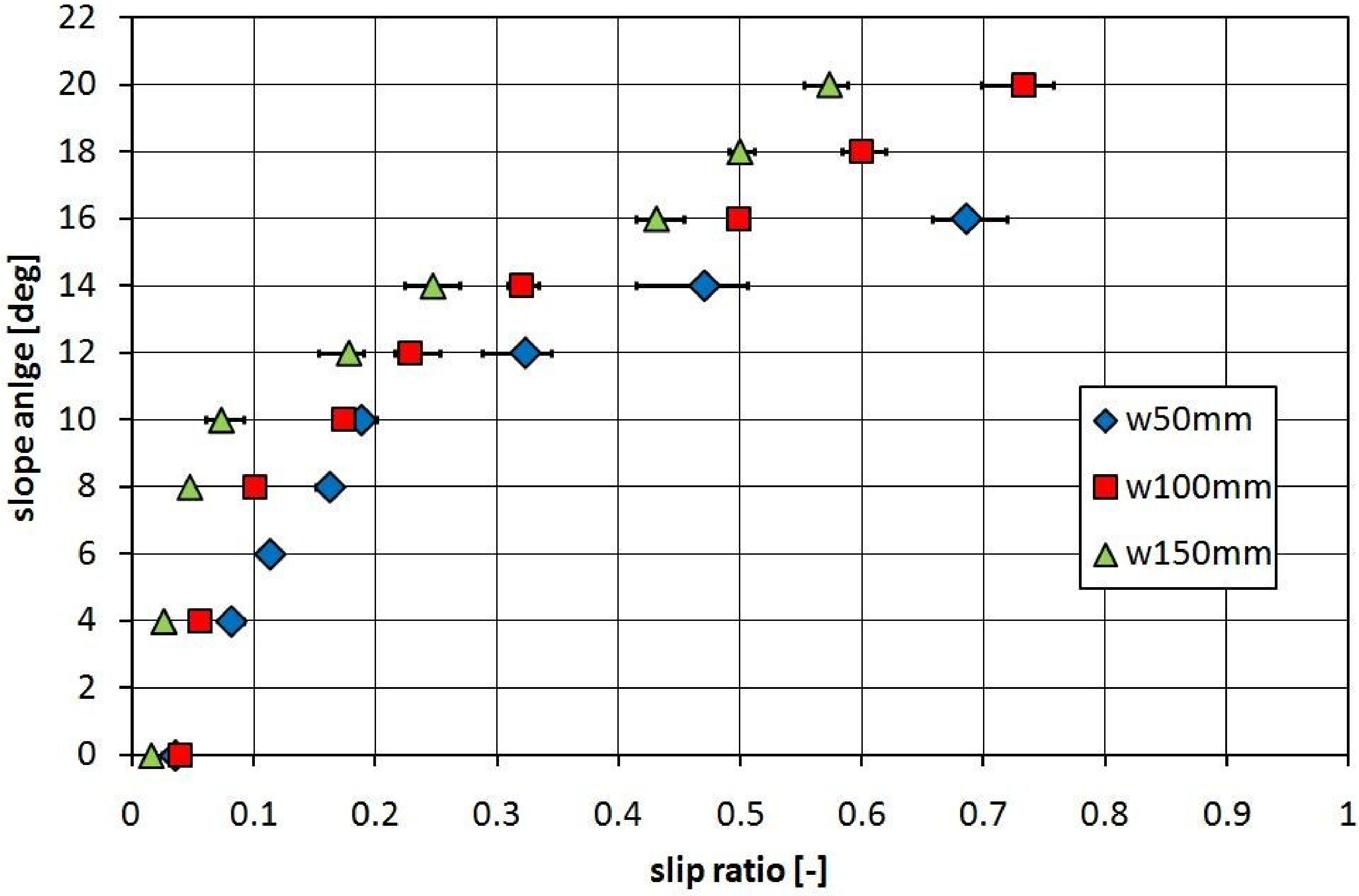


（width = 100mm）

With Larger Diameter

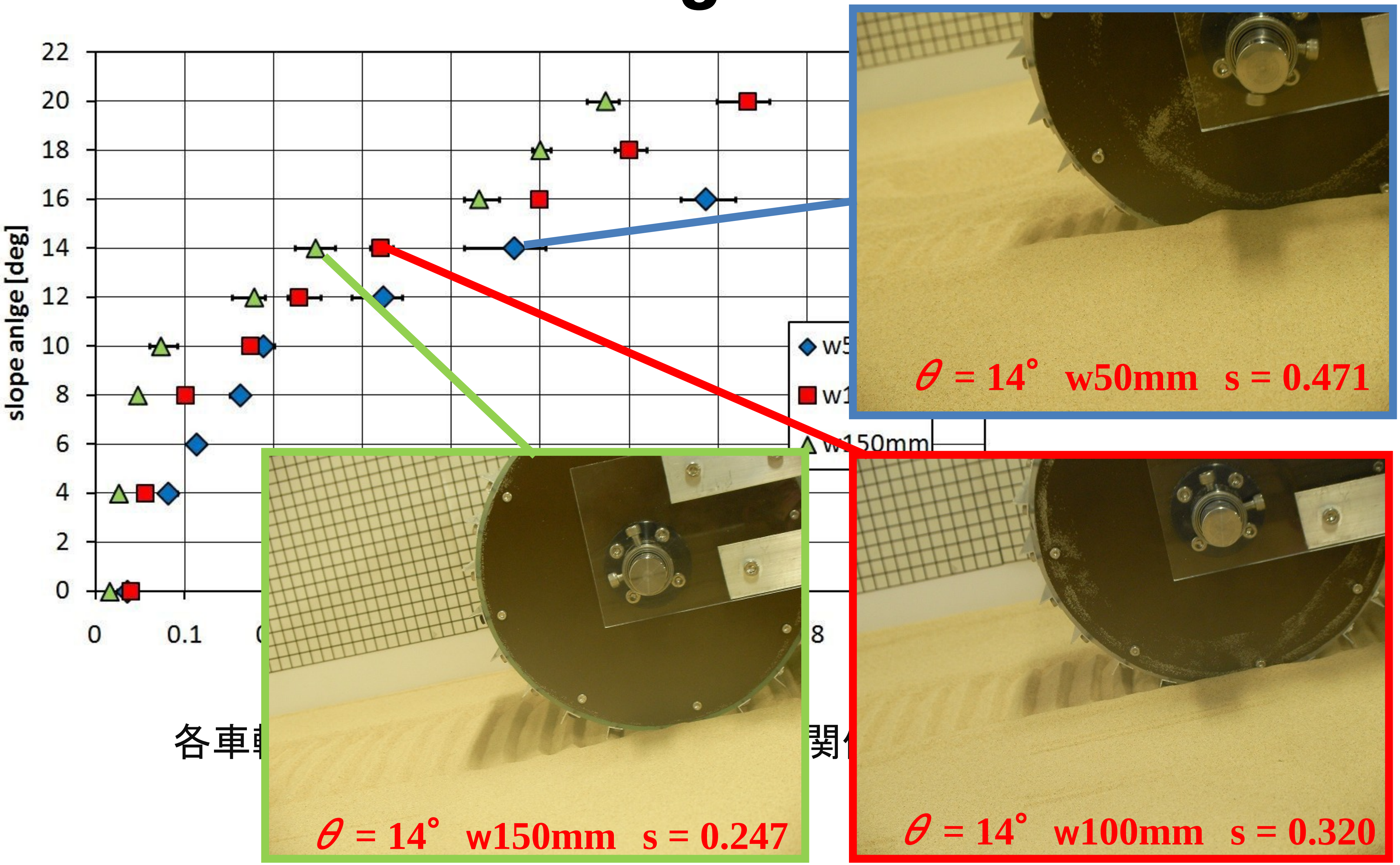


With Larger Width



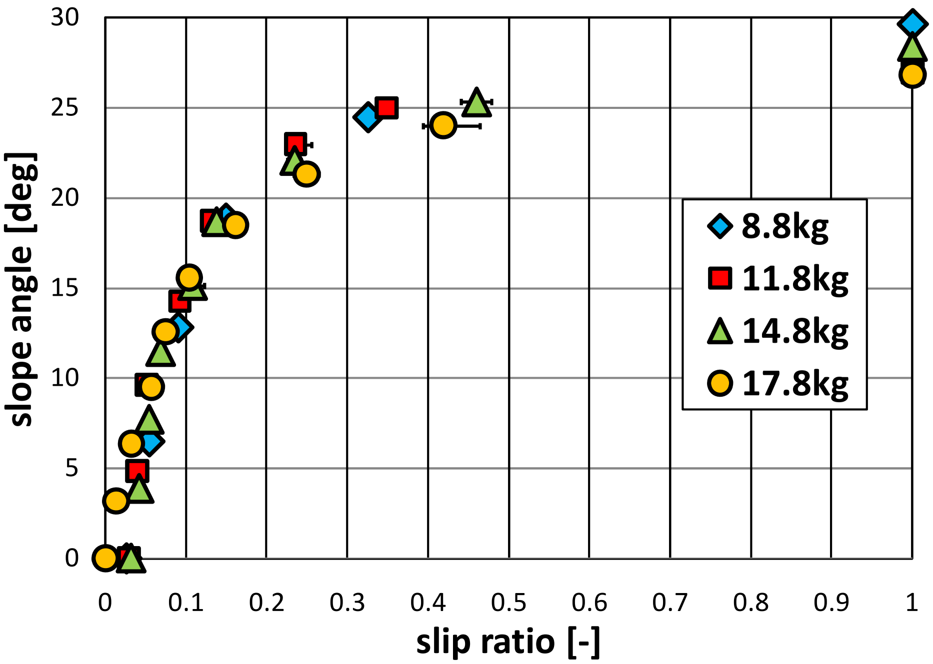
（D = 200mm）

With Larger Width

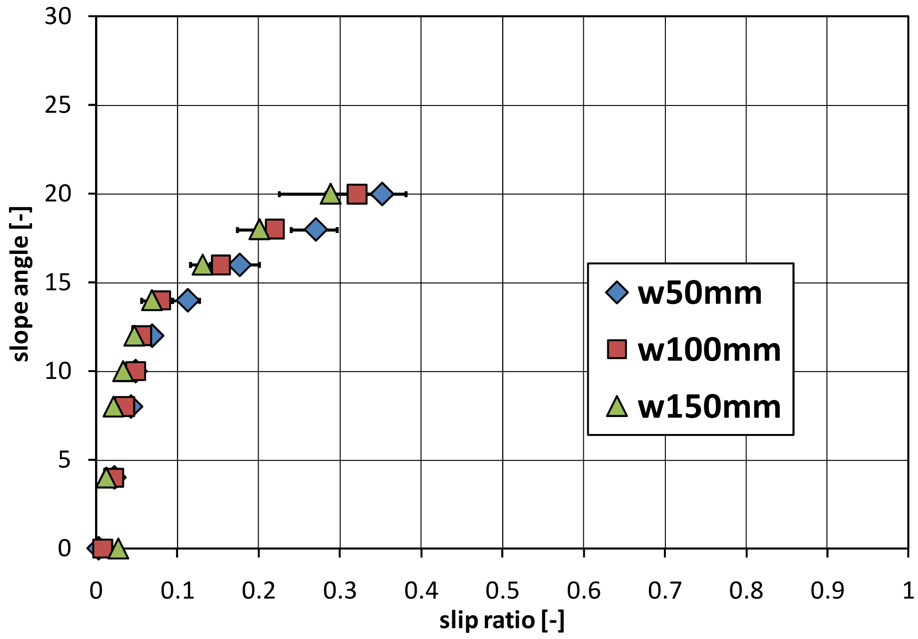


Comparison of Track and Wheel

track



wheel



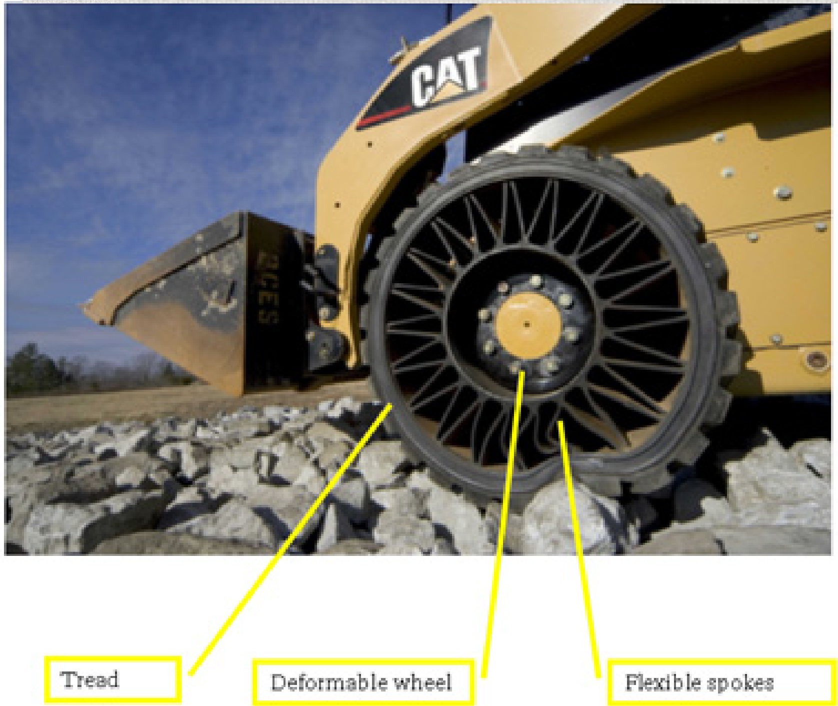
Q: How can we improve the traction performance of the wheels?

- Yes
- with increased contact area
- with decreased wheel sinkage

Deformable Tire

Example:

Michelin Tweel®



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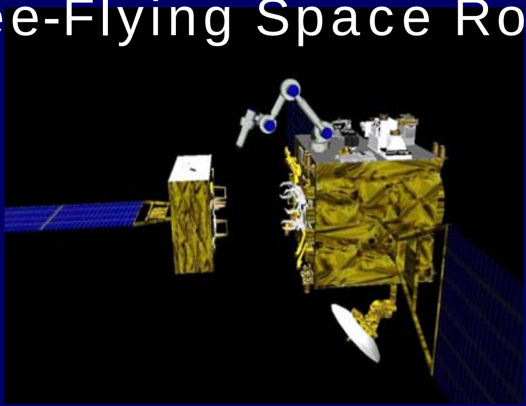
Summary

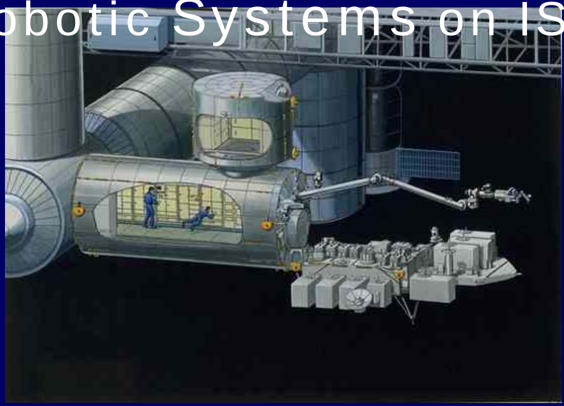
- The traction performance was experimentally studied to compare *track* (mono-crawler) and *wheel* (inline wheels).
- The slope climbing condition was equivalently tested by the increased horizontal load.
- The track showed higher performance than wheels.
- The track performance can be modeled like a surface friction, with very small sinkage related resistance.
- The wheel performance is largely disturbed by the wheel sinkage.
- But the performance of the wheels can be improved with grater diameter and width, which resulting in smaller sinkage.

The Space Robotics Lab.
Dept. of Aerospace Engineering
Tohoku University, JAPAN
Directed by Prof. Kazuya Yoshida
yoshida@astro.mech.tohoku.ac.jp
http://www.astro.mech.tohoku.ac.jp/home-e.html

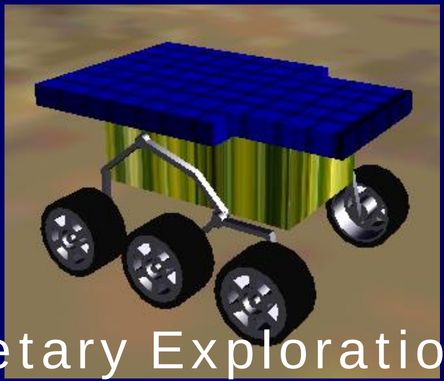
Free-Flying Space Robot



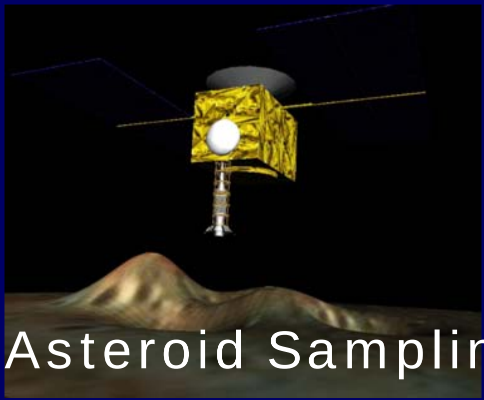
Robotic Systems on ISS



The SPACE ROBOTICS Lab.



Planetary Exploration Rovers



Asteroid Sampling