Effects of Percussion on Lunar Regolith Excavation Forces.

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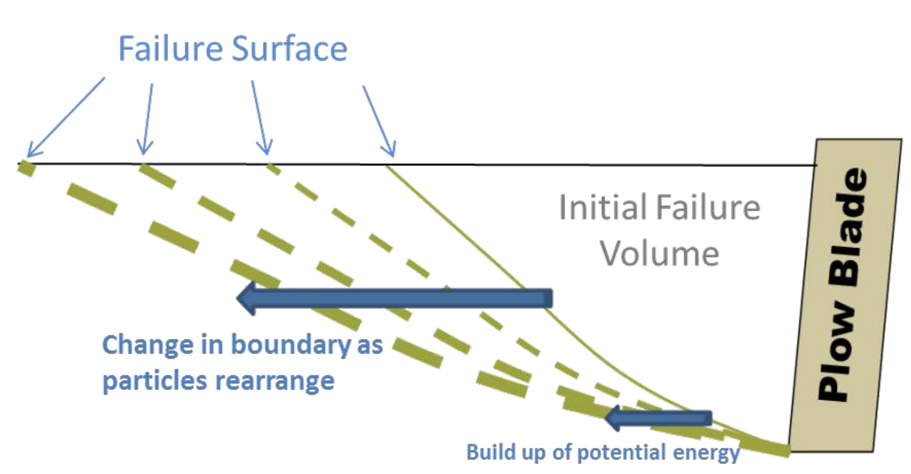
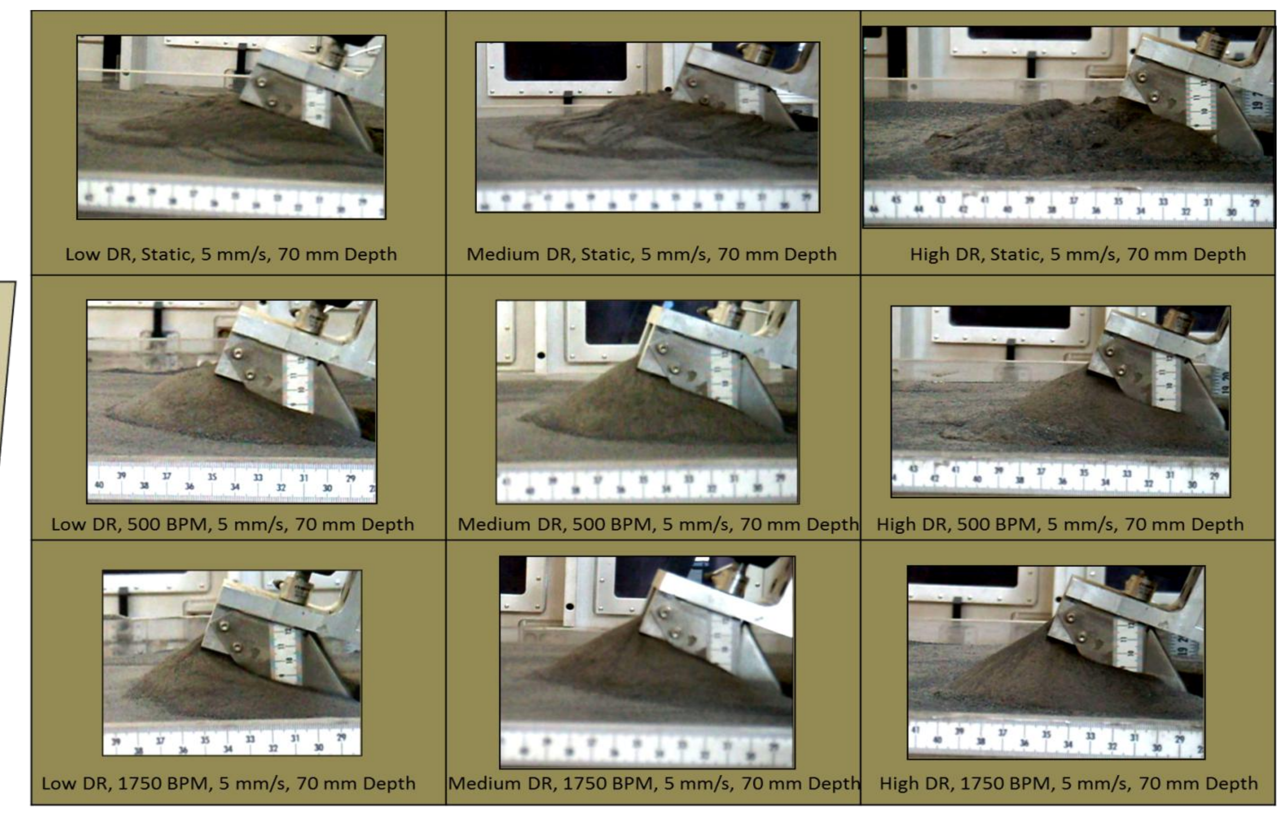
HONEYBEE ROBOTICS
Exploration Technology

Ten Second Summary

The purpose of vibratory and percussive scoops is to reduce excavation forces during material acquisition and to allow easier discharge of material during material gravity transfer - something that was witnessed during operation of Mars Phenix scoop [1]. Vibration (as opposed to percussion) occurs when the motion is in a particular direction without any impacts. This is akin to a sonic toothbrush. Percussion occurs when there is an impact onto the blade – e.g. jack hammers that are used to break up concrete. Using percussive scoops is not new, some commercial hammer drills include a scoop as an attachment. To use these scoops, the hammer drill is switched to hammer-only mode.



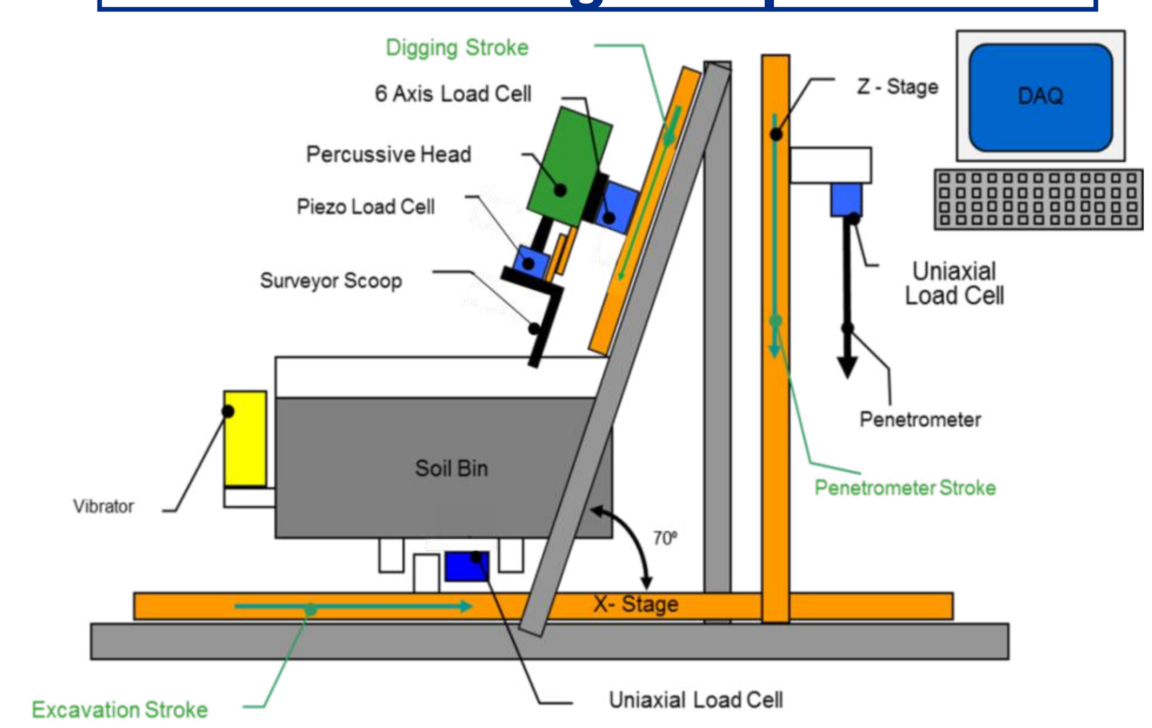


System Overview

An experimental setup testing two percussive scoop systems was tested in lunar simulant and is shown in Figure 1. The scoop used a simple brushless DC motor to power an offset mass by way of a pair of helical gears. Two slightly different designs were used, whereby the plane of vibration of the offset mass was oriented differently relative to the direction of scooping. Figure 2 shows a model of the two scoop designs and test data. The scoop used for these excavation tests is similar to the scoop used by the Lunar Surveyor mission. Using similar geometry facilitates more meaningful comparison with the Surveyor data, as well as with tests performed by others using the same or similar geometry. Excavation tests were performed in JSC-1, a lunar mare simulant. The shear strength of a soil is dependent upon three critical factors: the cohesion, the effective stress, and the internal friction angle. The magnitude of the internal friction angle is based on two different components: surface-to-surface sliding friction and soil particle relative movement, which is known as dilatancy. When percussion is applied to an excavator implement in dry JSC-1A soil, at the proper frequency and impact energy, the magnitude of dilatancy is reduced. A reduction in soil dilatancy causes the shear strength of the soil to decrease. The decrease in soil strength is made manifest through a reduction in the baseline excavation draft force and an alteration in the defining geometry of the tool-soil failure volume. The manner in which percussion influences soil strength is dependent upon several variables. Six variables were examined in this work: percussive frequency, percussive impact energy, excavator speed, excavator depth, angle of attack, and in-situ relative density.

Due to the plausibility of reducing in-situ soil shear strength, future low gravity excavator designs do not have to be constrained to the high body forces required in static excavation. The analysis provided in this work gives information regarding which parameters are most critical in the design of future percussive systems.

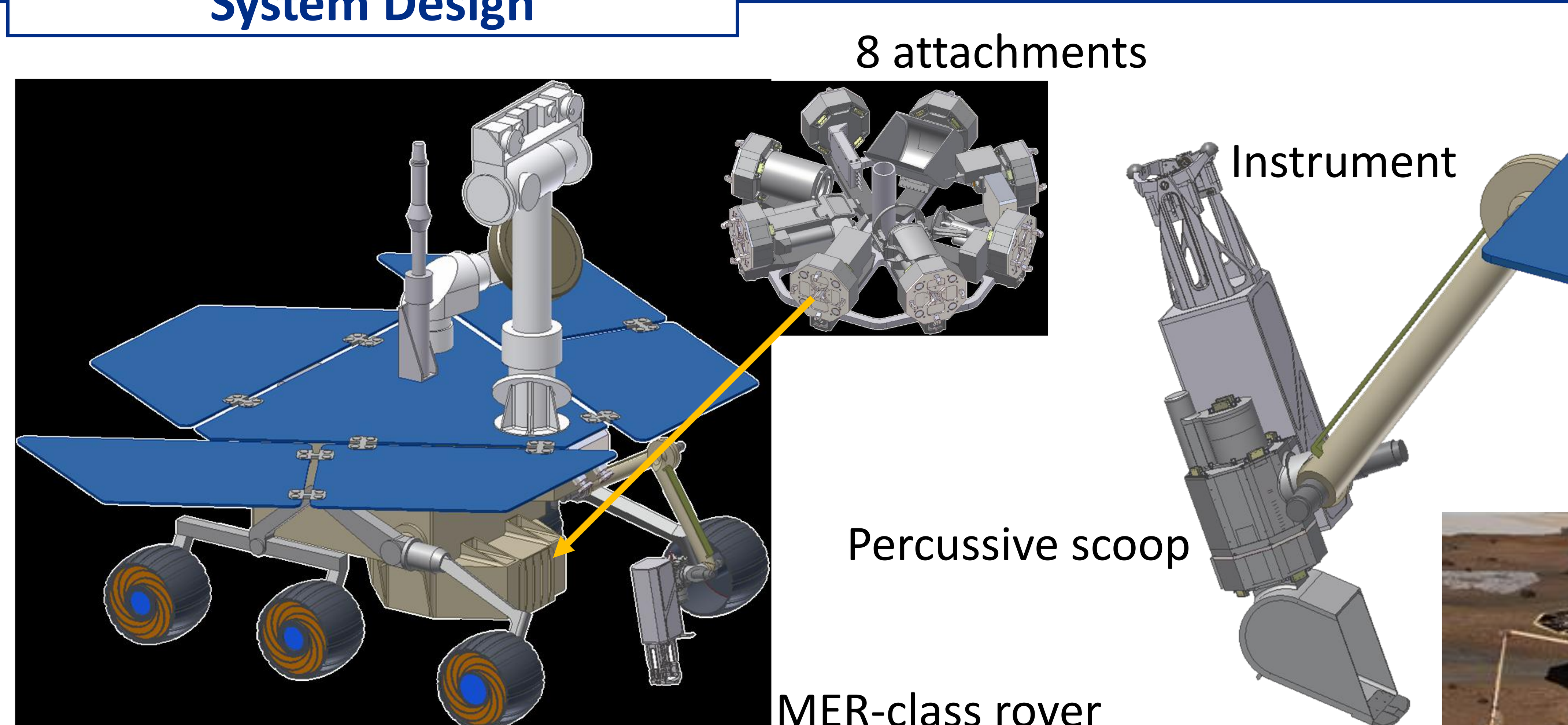
Testing Setup

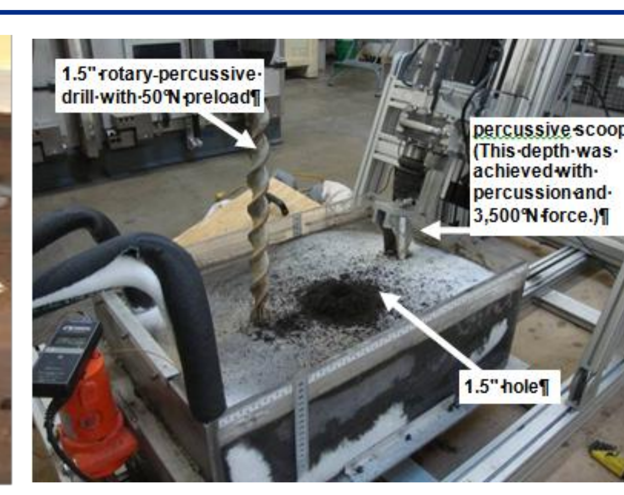


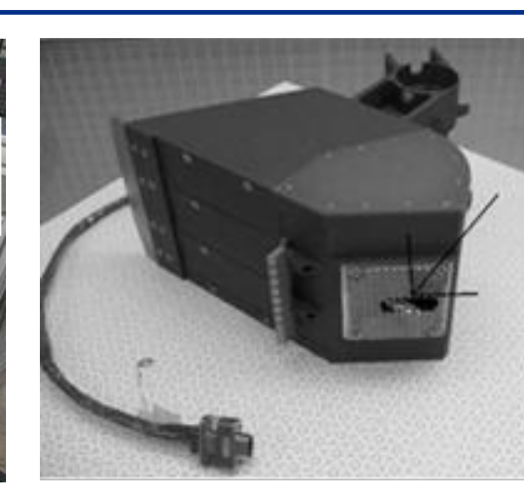
Controlled experiments needed to be performed to gain an understanding of the percussion-soil interaction

Not knowing beforehand what factors had the strongest influence, a robust test stand was designed and built to enable several different test variables.

System Design

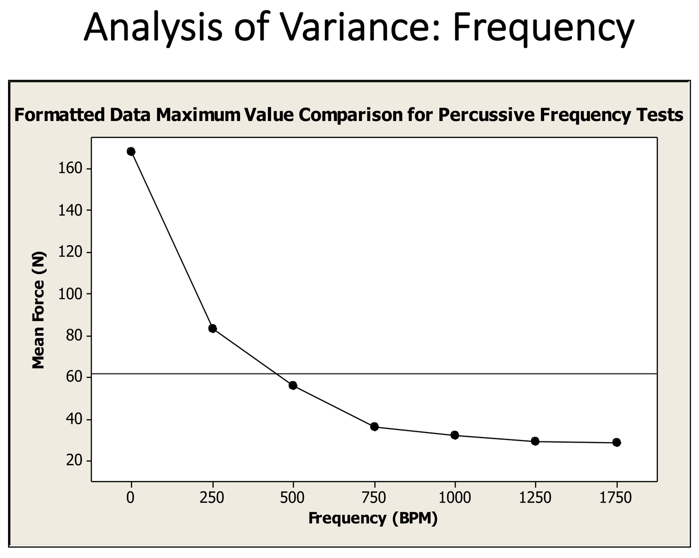






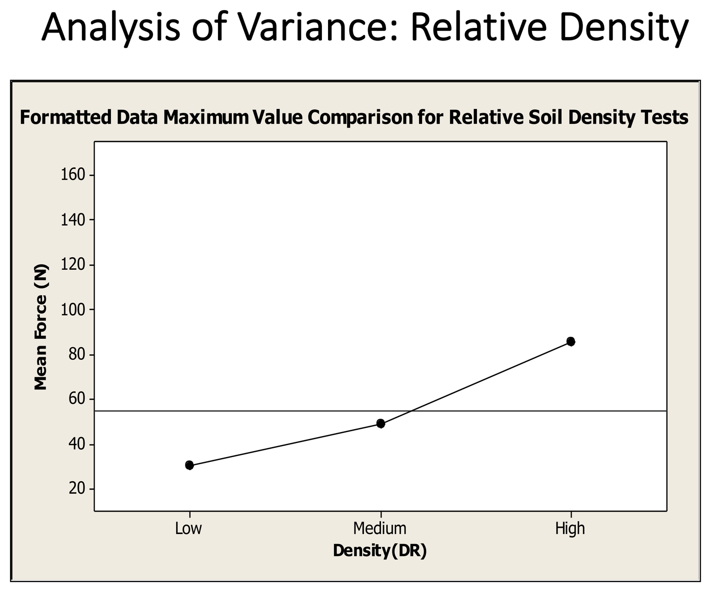
Data Analysis

Analysis of Variance: Frequency



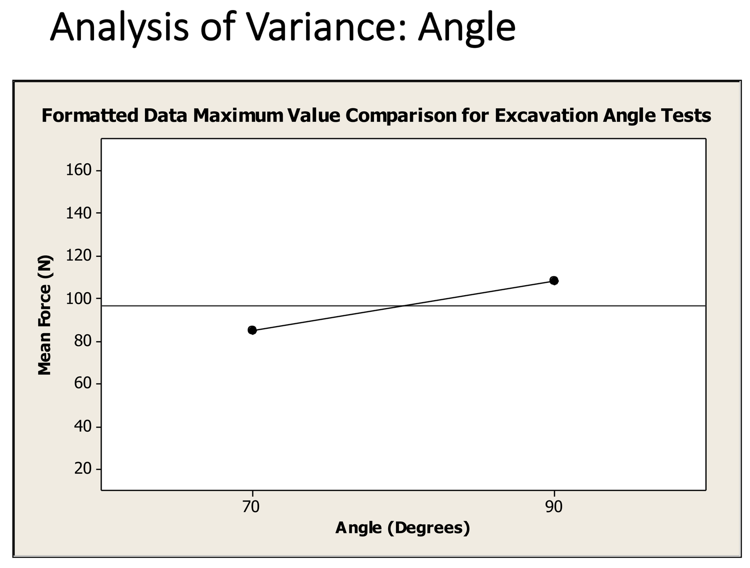
Points of Consideration
- Relative density is mitigated at higher frequencies
- Force gradient with respect to depth is greatly diminished
- No major improvement past 750 BPM

Analysis of Variance: Relative Density



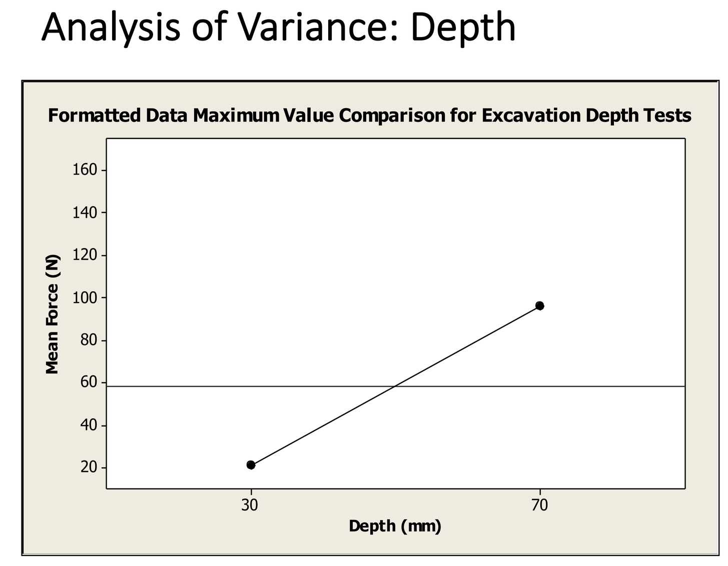
Points of Consideration
- Percussion eliminates the effect of relative density by removing dilatancy
- Asymptotic limit increases with relative density due to increase in number of particles under influence of surface friction

Analysis of Variance: Angle



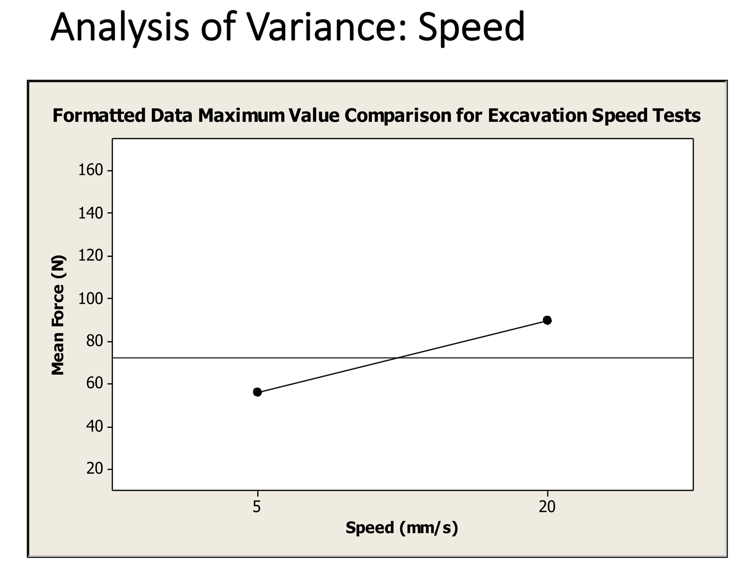
Points of Consideration
- A change from 70° to 90° decreases the effectiveness of percussion at higher frequencies

Analysis of Variance: Depth



Points of Consideration
- Percussion greatly mitigates the effect of increasing scoop depth

Analysis of Variance: Speed



Points of Consideration
- The influence of speed is higher for percussive excavation than for static
- Higher speeds require higher frequencies to overcome a lower settling time and maintain a state of disengagement