DETERMINING MARS SOIL PROPERTIES FROM LABORATORY TESTS, DISCRETE ELEMENT MODELING, AND MARS TRENCHING EXPERIMENTS.

J.B. Johnson[1], M.A. Hopkins[1], T. Kaempfer[1], J.M. Moore[2], R.J. Sullivan[3], L. Richter[4], N. Schmitz[4], and the Athena Science Team. [1]U.S. Army Engineer Research and Development Center (Jerome.B.Johnson@erdc.usace.army.mil); [2]NASA Ames Research Center; [3]Cornell University, [4]Institute of Planetary Research, German Aerospace Center.

Introduction: We report on preliminary comparison of discrete element method (DEM) simulations of laboratory tests of the Mars Exploration Rovers (MER) wheel/soil interaction. This is a prepatory step to analyzing MER martian data to determine Mars soil properties. Knowledge of Mars soil properties improves the ability to interpret Mars surface geologic processes and develop engineering analyses for future landed missions. Soil properties of particular interest include the density, mechanical strength and compaction, near-surface stratigraphy and spatial heterogeneity of properties. Wheel tracks from the MER rovers indicate layering of soils of different composition by digging underlying soil to the surface **(Fig.1)**. Reconstructing the original stratigraphic position and heterogeneity of soil layers, combined with compositional and physical properties measurements, can point to the geological formation processes. Interpreting wheel track images

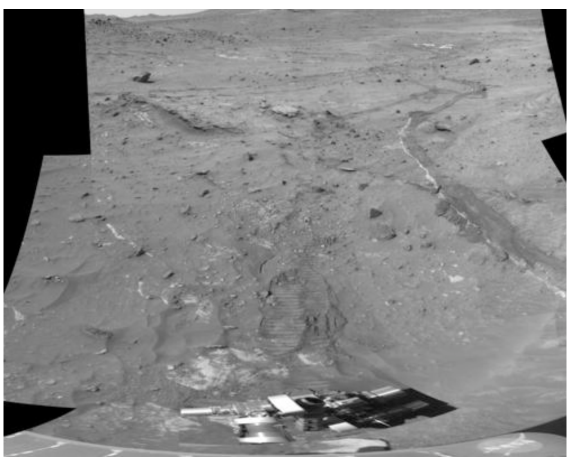

Figure 1. MER Spirit tracks and disturbed soil near Tyrone showing overturned bright soil, clods and push ridges (NASA/JPL-Caltech/Cornell [1]).

and MER wheel motor currents to derive soil movement paths and soil properties requires a combined approach of analytical and numerical simulation of laboratory and Mars data.

Approach and Technique: Laboratory tests of MER wheel trenching experiments and analysis of MER wheel currents is used to estimate soil strength (**Fig. 2**). Interpretation of wheel trenching tests proceeds by first analyzing wheel motor currents to estimate wheel torque during MER trenching events.

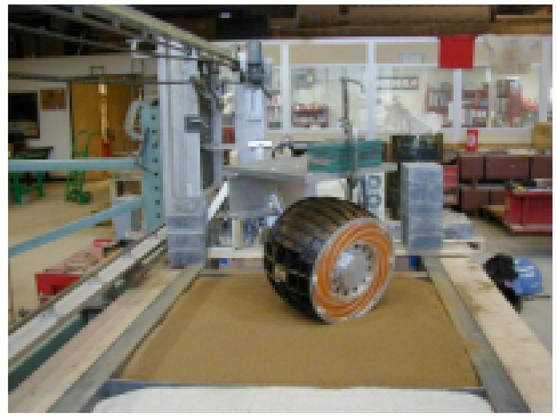

Figure 2. MER Wheel laboratory experiment at the Cornell George Winter Laboratory (Sullivan).

Terrestrial laboratory tests using an equivalent MER wheel and a simulant of Mars regolith are used to calibrate MER wheel torque/electric current relationships for digging experiments (**Fig. 2**).

Figure 3. MER wheel test in layered soil at the German Aerospace Center (Richter and Schmitz).

In combination with images of soil disturbances from testing, wheel torques are used to estimate soil cohesion and internal friction parameters using the Mohr-Coulomb soil strength model [2].

Additional laboratory tests using a MER wheel in a test track are used to examine the displacement of soil layers as well as to develop a semi-empirical model of wheel/soil interaction (**Fig. 3**) [3]. The latter is used to determine – through model inversion -- some of the soil strength and deformation properties from measured depth of the wheel ruts on Mars and reconstructed vehicle slippages.

A numerical simulation model of MER wheel interaction with soil was developed using the DEM to describe the effects of wheel/soil interactions as a means to improve MER wheel analysis (**Fig. 4**). For MER analyses, the important geometric aspects of a specific soil test (e.g., wheel geometry, soil compaction, trenching, or disturbance of layered soil) are represented by the DEM, along with the soil properties (grain size, and particle contact cohesion and friction) to directly represent the experiment of interest. Once the soil micro-scale parameters are known the model is used to simulate specific MER equipment behaviors and soil deformation processes.

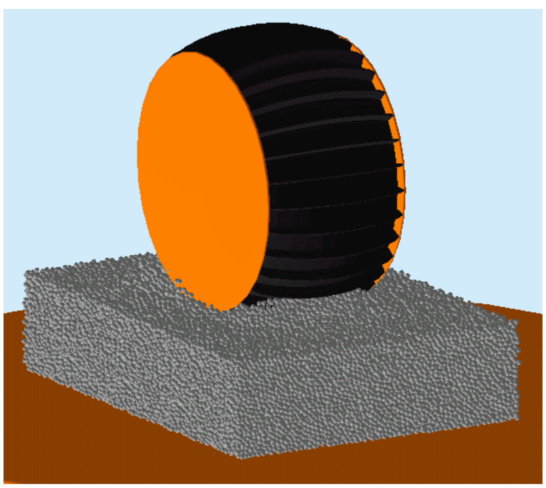

Figure 4. DEM simulation of a MER wheel in soil (Hopkins and Kaempfer).

Progress

A description of the DEM approach and its conceptual application to MER analyses is given in [4]. The DEM simulation (**Fig. 4**) explicitly models the dynamics of MER wheel interaction with soil particles. Both trenching and wheel traversing, with wheel slippage, is included and simulations of laboratory tests are being used to calibrate the DEM model. Once the DEM is calibrated it will be used to simulate Mars conditions to analyze MER rover measurements. Experience indicates that when DEM simulations accurately replicate test conditions, selected granular material properties are very close to their actual values.

Conclusions: Methods to determine Mars soil stratigraphy and physical properties have been developed and used to simulate laboratory experiments of MER wheel/soil interaction to determine DEM parameters. The calibrated MER wheel DEM will then be used, in combination with laboratory tests of MER wheel interaction with Mars regolith simulant, to analyze MER martian data to help interpret Mars geologic processes and soil engineering properties.

References:

[1]http://marsrovers.nasa.gov/gallery/press/spirit/20060530a/2NP807ILFARCYL00P1986L000M2-A835R1_br.jpg. [2] Sullivan et al. (2007) 38th Lunar and Planetary Science Conference, Abstr. 2084. [3] Richter et al. (2006). In: Proceedings, *10th European Conference of the International Society for Terrain-Vehicle Systems (ISTVS)*, Budapest, Oct. 3-6http://www.lpi.usra.edu/meetings/lpsc2007/pdf/2084.pdf. [4] Johnson et al. (2006) 37th Lunar and Planetary Science conference, Abstr. 1578, http://www.lpi.usra.edu/meetings/lpsc2006/pdf/1528.pdf.