Günter Kargl, Norbert I. Kömle, Andrew J. Ball and Ralph D. Lorenz (Editors)

PENETROMETRY IN THE SOLAR SYSTEM II

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Participants not shown: N.I. Kömle, J. Grygorczuk, L. Richter, S. Tanaka

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SECOND INTERNATIONAL WORKSHOP ON PENETROMETRY IN THE SOLAR SYSTEM

Proceedings of a Workshop
held at the
Space Research Institute, Austrian Academy of Sciences, Graz, Austria
25-28 September 2006

This workshop brought together workers in the narrow confluence of diverse fields that constitute solar system penetrometry. Specifically, this refers to the emplacement of instrumentation at low or high speed into the surface of a solar system body, and the recovery of information about that surface, usually its mechanical and thermal properties and its composition. The distinction was re–iterated, but sometimes ignored, that a 'penetrometer' is an instrument, inserted at low speed, while a 'penetrator' is a high speed, ballistic vehicle (although a mole is self–propelled, hence a low speed vehicle; as its advance allows to infer some mechanical soil properties, it is also an instrument).

While the first workshop, in 1999, was devoted largely to theoretical methods, historical discussion, laboratory work and future plans, the second workshop featured much discussion of the actual results from the *Huygens* impact on Titan's surface, together with anticipation of results from *Philae*, the Rosetta lander now in flight, and wheel indentation studies from the *Mars Exploration Rovers*. The Mars projects featuring penetrators and moles that had flown in the intervening years, namely *DS–2* and *Beagle–2* respectively, sadly failed to land nominally and to return data. Participants look forward hopefully, as they did in 1999, to the realization of penetrators to the Moon or perhaps Europa.

A new theme in the workshop was a biological one. By coincidence, the presentations of the two authors of this preface both featured 'cat litter' (or sepiolite, which is itself a mineral!) or measurements thereon; several talks considered self–penetrating moles, and one biomimetic drill concept presented was specifically inspired by the two–part ovipositor drill of the wood wasp. It was realized by the participants that one particular problem faced in penetrometry (especially in low gravity environments) is how to cope with the reaction forces generated during penetration, and that perhaps submarine mammals may have evolved a solution to this problem. (We ourselves have since researched this topic — we note with interest that dolphins mate face to face, and that a male dolphin may have some prehensile control of his reproductive organ, which is normally recessed in a genital slit to minimize drag. The reaction force problem, however, seems to be addressed by locking flippers by hydrodynamically generating lift in a forward swim – techniques that sadly offer us little utility for spacecraft work.)

The workshop was hosted by the *Space Research Institute* in Graz, which offered its convenient and appreciated facilities and services. The workshop featured three days of presentation among the more than 20 participants from nine countries. These three days were spread over four calendar days, allowing ample time for discussion. Next to discovering and admiring the heart of the beautiful city on the Mur, as well as allowing a congenial excursion to a chocolate factory proposed quite ‘high speed sampling tests’. It was noted by several participants that a considerable literature exists on the penetrometry of foodstuffs, the technique being used for example to determine the fat content of cheese. A nearby castle revealed an impressive collection of medieval penetrometers.

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Figure 1: Some medieval penetrometers.

SOIL PENETRATION ANALYSIS OF MOLE PENETROMETERS: REFLECTIONS ON A METHODOLOGY CONSIDERING THE PHYSICS OF SANDS

P. Coste*, L. Richter†

This paper is dedicated to the memory of Dr. Valeryi Vassilevich Gromov, who passed away on June 23 2006, and without whom neither the 'Mole' nor the 'Mole with Sampling Mechanism' could have been realized.

Abstract

This paper presents some thoughts about *Mole* penetration: it is put in relation with experiments and models from the 'Modern Physics of Sands'. This reflection derives in particular from experiments demonstrating how some shocks may consolidate sand, such as 'sticking' a stick buried in sand. The current analysis of the *Mole* penetration is put in parallel with the modern physics of sands. The somewhat amazing *Stuck Stick* experiment, proposed in the literature related to this *Modern Physics of Sand*, and the *Stuck Mole Stick* experiment derived from this are reported (both were demonstrated to the IWPSS2 audience). Potential benefits of a renewed theoretical approach are identified. This paper, solely qualitative, intends to stimulate the reflection and encourage a deeper analytical approach of the *Mole* penetration — if necessary!

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1 Introduction

Sand is a type of granular material with a very peculiar behaviour: local interactions between grains are driving the material properties. It was shown e.g. that local arches of grains support local loads, but are easily broken by external forces or shocks. Sand analysis has challenged many scientists, but is currently progressing. Penetrometers or *Moles* are made to penetrate sandy soils or similar materials, using a shock mechanism as regular as a clock. However, many penetration analyses consider a soil model which is quasi–continuous: the penetration prediction models or analyses of test results use quasi–static parameters derived from civil engineering soil tests; then equilibrium of forces or an energy balance is established – and adequately adjusted. This paper intends to point out, mainly qualitatively, a number of topics relevant to physics of sands and related to the *Mole*. It is suggested that an approach based upon the physics of sands should be considered and included in penetrometry, in order to improve the understanding of *Moles* and penetrating bodies' performance. This paper intends to point out, mainly qualitatively, a number of topics relevant to the physics of sands.

2 Mole Penetrometry

Most soil sub–surface investigation techniques are performed with penetration, either carrying various sensors to depth (e.g. thermometers) or in order to bring back samples for laboratory analysis. In the field of planetary soils exploration, the main investigation and sampling methods are:

- Scooping
- Penetrometry (at low and high speed)
- Drilling

Scooping is limited to surface sampling. High speed penetrators, with ballistic entry, are expected to reach a few meters depth on the Moon or the Mars surface. Only drilling and penetrometry allow penetration to a depth of several metres, necessary for sampling into subsurface regolith. Drilling is mostly used for rocks and solid materials; it may reach several tens of metres, given sufficient thrust and energy.

A low speed 'penetrometer' or *Mole* is a cylinder with a sharp tip, inserted into a granular medium by repeated internal shocks. Penetrometry is best used for sand and other granular materials similar to regolith. In addition, sampling may be performed at a desired depth by opening a cavity behind the tip and then closing it to retrieve the sample. Penetrometry may be considered as a process causing only little destruction of the surrounding soil, as the grains are generally only slightly displaced (instead of being cut into chips and transported out of the hole). Mole penetration through operation of the inner shock mechanism needs very low power, which is of interest for planetary missions, where maximum power is limited, but often the total process duration is less severely restricted.

2.1 Shock mechanism principle

The *Mole* penetrometer consists essentially of a tethered, tubular body with a pointed end; this end is struck periodically by the internal shock mechanism, which slides inside to minimize the recoil. The penetration is usually more or less vertical. A cycle of the shock mechanism is depicted by the series of sketches shown in Figure 1. Note that two shocks occur: following the main shock of the hammer on the anvil, due to the release of the compressed spring, a second shock occurs when the sliding mechanism falls back.

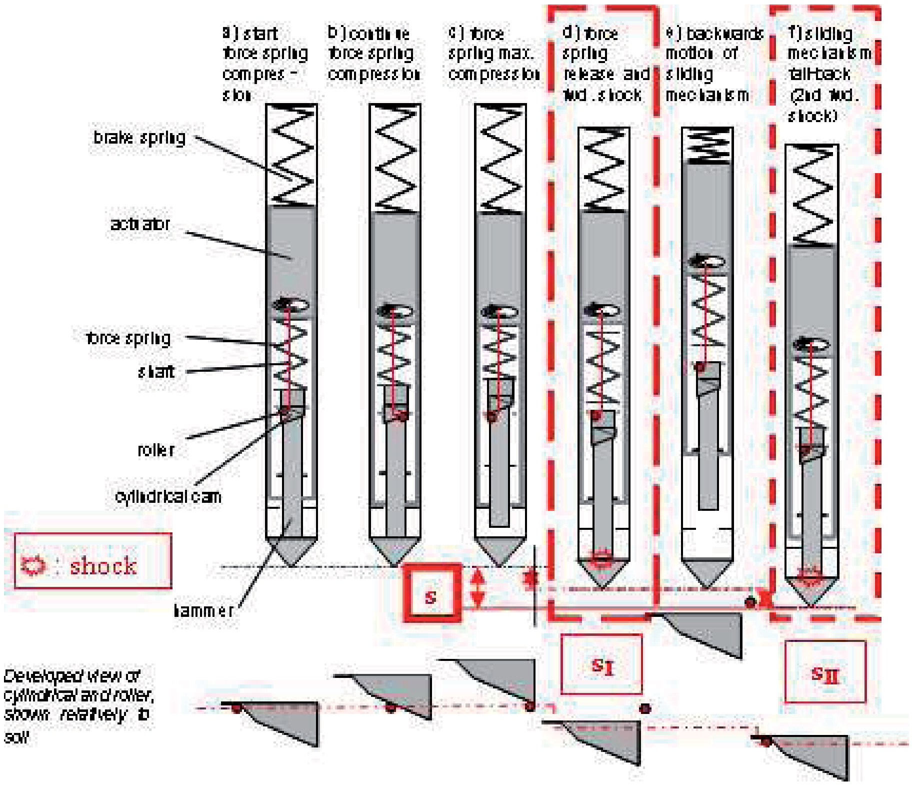

Figure 1: Mole, sliding shock mechanism – sequences of a shock cycle (from Richter et al., 2006).

3 *Mole* penetration analysis: current engineering approach and energy transfer model

In the current engineering approach, the energy transfer model combines the basic elements of the diagram (Figure 2) to predict the *Mole* intrusion into the soil.

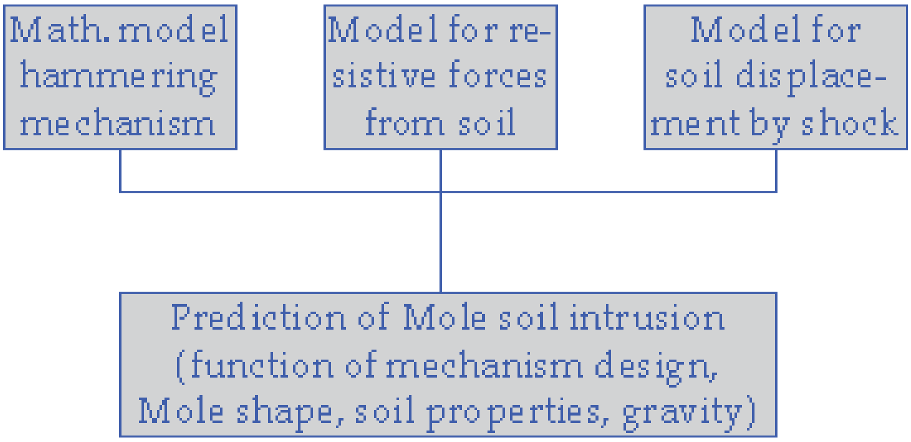

Figure 2: Energy transfer model of Mole penetration (from Richter et al., 2006, Fig. 5–1).

3.1 *Mole* shock mechanism: energy model

The mathematical model of the hammering mechanism includes the shock mechanism parameters with all masses as well as spring and internal impact losses (cf. Figure 3). It is able to compute the shock energies delivered internally in a single cycle. An energy method has been preferred to a dynamic model which would demand a direct formulation of the forces and of their equilibrium.

3.2 Soil model: resistive forces

The soil model predicts the resistive forces, due to normal compression at the tip and lateral friction of the main body. A penetrometry analysis with current methods considers generally the following engineering parameters of sand:

- Density
- Compressive strength
- Lateral friction

It takes occasionally into account:

- Granulometry
- Loss angle
- Bulk modulus

It does not generally address (directly):

- Soil compressibility
- Affected volume
- Internal stresses in the surrounding soil
- Thermal aspects

Models of quasi–static penetration, based on experimental data, are used for initial estimations. Penetration resistance and maximum penetration depth are also predicted on the basis of experimental data. Soil models of penetration by shocks are derived from pile driving data and from previous *Mole* experiments.

3.3 *Mole* penetration model

The three previous models of the *Mole* mechanism, the soil resistance and the soil penetration by shocks are combined to predict the *Mole* penetration. Experiments of *Mole* penetration in soil are used to refine the initial predictions and to determine the permanent soil displacement achieved during a single *Mole* shock cycle.

The *Mole* displacement is particular, due to its internal shock mechanism. Figure 3 shows a typical displacement vs. time over a shock cycle; these data are coming from a *Mole* instrumented with an accelerometer. It appears that the first shock, corresponding to the impact of the launched hammer, generates a displacement with overshoot, with a recoverable elastic component and a permanent plastic displacement; the second shock, when the mechanism falls back, induces essentially a plastic displacement (usually smaller than the first one). The sum of these plastic displacements is the advance s per cycle (typically about $1.5 - 2$ mm in Mars simulant). The soil reaction force R is assumed constant over the advance (typically equal to $40 - 50$ N). The tether friction is included in the model, unless no hole collapse is expected. The energy transfer model, calibrated with '1 g' experiments, predicts penetration under Mars gravity as shown in Figure 4.