MECHANICAL PROPERTIES OF PLANETARY ANALOG MATERIAL AS INFERRED FROM PENETRATION TESTING.

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Introduction: Investigation and characterization of the subsurface of extraterrestrial planetary bodies using penetrometers are of high interest. Because they offer reliable scientific outcomes and due to their mechanical simplicity, this makes them desirable instruments for planetary investigations. Static Penetrometers are deployed using lander/rover where the maximum force of penetration is a direct function of the weight of the lander/rover on their target planetary body. Therefore, penetration forces are proportional to the mechanical and physical properties of the surface and subsurface of these planetary bodies as well as its gravity [1]. The axial downward movement of the penetrometer through regolith is closely related to the problem of driving piles in foundation engineering which uses bearing capacity theory to explain penetration forces [2]. The downward movement of the penetrometer through regolith is opposed by two reaction forces: the base or cone resistance, which pushes against the cone and sleeve friction, which acts up on the lateral side of the penetrometer [3]. Penetration into regolith materials is directly proportional to the effective unit weight of the regolith (γ), bearing capacity factor (N_q), depth of penetration (D) and friction angle (φ) [3].

The main objective of this research is to estimate the bearing capacity factor (N_q) experimentally based on forces of penetration for martian analog material (JSC Mars-1). Our choice of JSC Mars-1 because it is considered as one of the best martian analoge material [4]. From penetration forces as well as the knowledge of some mechanical properties of JSC Mars-1, one can estimate the bearing capacity factor (N_q) under different levels of compaction. (N_q) varies from one type of material to another due to intrinsic regolith properties. Knowledge of (N_q) will help us approximate and predict the force of penetration under different levels of compaction to simulate the conditions on Mars such as density and gravity.

Experimental Methods and Equipment: Penetration testing is performed in constant velocity mode at a rate of 2 mm s^{-1}. The test system consists of a constant-speed motor driving a linear actuator screw that pushes the probe down and pulls it back out Fig 1. The probe does not rotate during testing. A load cell is mounted between the force actuator and the probe for force measurement, both in and out. The electric actuator pushes the probe down to a designated depth and stops there while continuously measuring the required force. Samples are prepared by filling a 16 cm diameter and 24 cm deep cylindrical bucket with 27.5 kg of dry JSC Mars-1. Then, the bucket is shaken in order to homogenize and compact the regolith to the desired height. All possible care was taken to obtain a uniform density throughout the column regolith. Penetration testing is done only once per sample preparation.

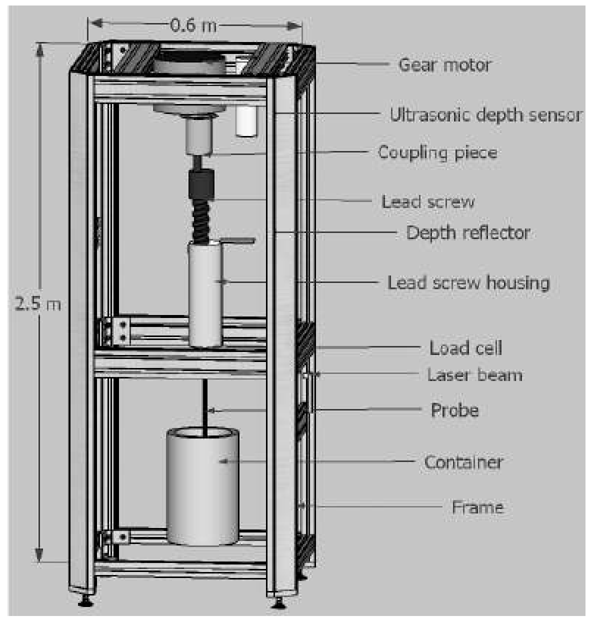
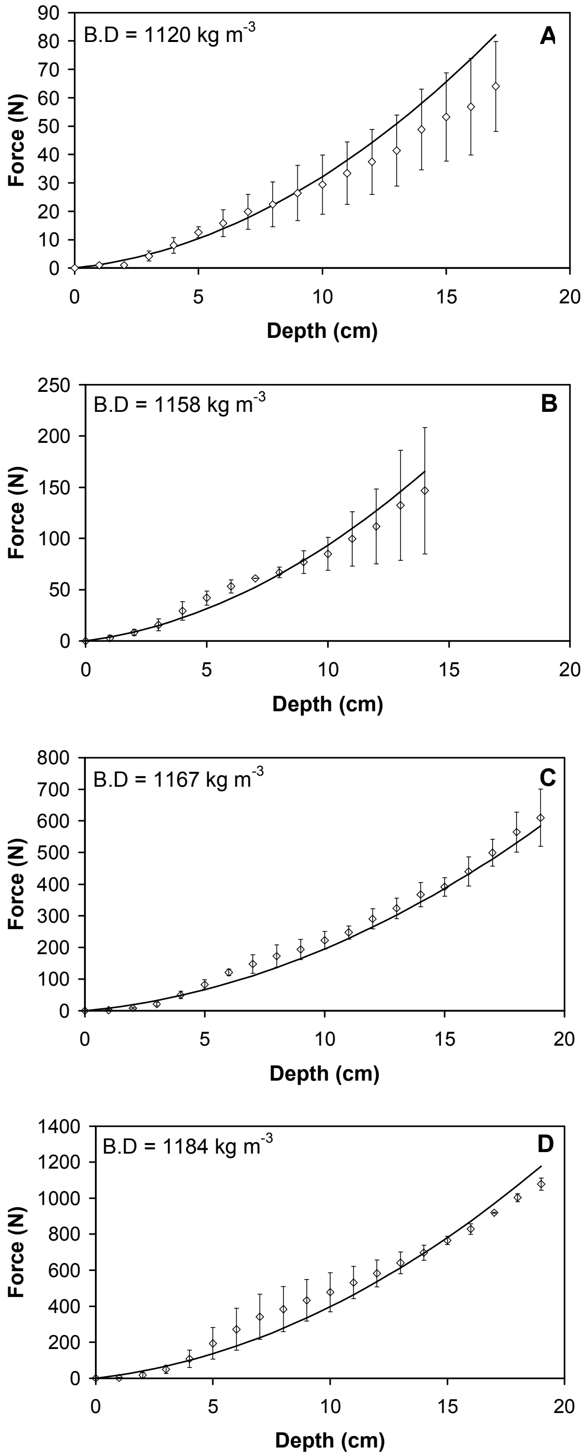


Figure 1. The penetration testing apparatus.

To determine the bearing capacity factor (N_q) from forces of penetration, a cylindrical container was filled with JSC Mars-1 with a measured bulk density of 1120 kg m^{-3}. Insertion and removals were conducted at this bulk density using 1.2 cm diameter probe. JSC Mars-1 poured out of the container and re-poured in for each penetration test. JSC Mars-1 was adjusted to the same bulk density of 1120 kg m^{-3} for two more penetration testing. The average force of the three penetration testing is calculated and (N_q) factor is determined at each data point. The average of (N_q) was determined and implemented in a matlab code to determine the theoretical force of penetration based on the knowledge of bulk density.

Results: Penetration force is a strong function of the density of regolith materials and increase with increasing bulk density [1]. Five different levels of compaction were prepared to achieve a bulk density of 1120, 1158, 1167, 1184 and 1241 kg m^{-3}. Figure 2 shows the forces of penetration as a function of depth under different bulk densities. Solid line represents the theoretical force of penetration based on the knowledge of the bearing capacity factor (N_q) and bulk density. Penetration forces increase with increasing the compaction level.



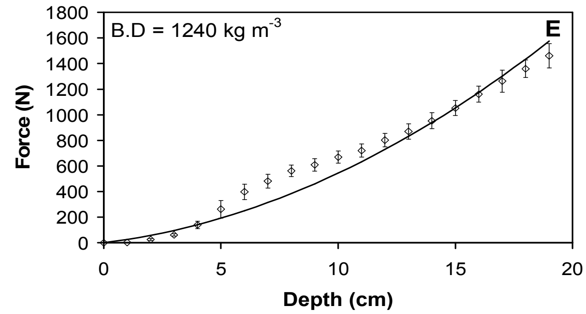


Figure 2. Penetration forces as a function of depth for different bulk density (D = 1.2 cm for A, B, C, D, and E, T.A = 60º) (For F, D = 1.9, T.A = 60º).

Figure 2 F shows the penetration force versus depth using a 1.9 cm diameter probe under a bulk density of 1184 kg m^{-3}. The (N_q) factor used for the theoretical force is the same as determined by 1.2 cm diameter probe (Fig. 3 D). Theoretical penetration curve is in agreement with the experimental data which supports the validity of the N_q factor under the same bulk density for different diameter probes.

Discussion: The total resistance force (F_T) during probes insertion into the subsurface is the sum of two forces; cone resistance (q_c) and sleeve friction (f_s):

$$F_T = q_C A_C + f_S A_S \quad (1)$$

Where A_c is the area of the cone, A_s is the area of the sleeve. The cone resistance can be calculated from [*5*]:

$$q_C = \gamma \times Z \times Nq\left(1 + \left(K \times \sin\varphi \times \frac{Z}{L}\right)\right) \quad (2)$$

Where γ is the effective unit weight of JSC Mars-1 (N m^{-3}), Z is the penetration depth (m), φ is the friction angle of JSC Mars-1 (degree), D_r is the relative density, K is the coefficient of lateral pressure at rest (dimensionless), N_q is the bearing capacity factor (dimensionless), L is the lateral extension of the slip lines (m).

Conclusions: The results of this investigation showed that the bearing capacity factor (N_q) vary under each level of compaction which increase with increasing the bulk density of the prepared samples. Knowledge of regolith mechanical properties determined from previous mission such as bulk density on Mars will be used and applied in the theoretical model for estimating the force of penetration under martian conditions.

References: [1] ElShafie A. et al. (2010) *ASR,*46, 327-336. [2] Murthy, V. N. S (2002) CRC. [3] Vesic, B. (1963) *High way research record*, 39, 112-153,[4] Allen, C. C. et al. (1998) *LPSC XXIX*, Abstract #1690. [5] Puech et al. (2002) *Offshore Technology Conference.*