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Development of Construction Materials Like Concrete From Lunar Soils Without Water

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Abstract

The development of construction materials such as concrete from lunar soils without the use of water requires a different methodology than that used for conventional terrestrial concrete. In this research project, a unique approach will be attempted that utilizes factors such as initial vacuum and then cyclic loading to enhance the mechanical properties of dry materials similar to those available on the moon. The application of such factors is expected to allow reorientation, and coming together, of particles of the materials toward the maximum theoretical density. If such a density can provide deformation and strength properties for even a limited type of construction, the approach can have significant application potential, although other factors such as heat and chemicals may be needed for specific construction objectives.

Introduction

Significant progress has been made in the area of space exploration in the past three decades. However, little has been done for development of construction materials for long-term shelters and work stations for man on other planets. For large-scale productivity on other planets, buildings and other structures are indispensable. Because of payload limitations on spacecrafts and the high cost of transportation, a prudent and efficient approach to construction on other planets requires that every effort be made to utilize the materials available on the planets themselves. The technique that is being developed in the Department of Civil Engineering and Engineering Mechanics is intended to utilize extraterrestrial "soils" to develop construction materials for building safe and serviceable structures.

Approach

Samples of lunar soil simulants of specimen size (3.0 × 6.0 inches) will be mixed in different proportions and will be tested under various levels of initial density and vacuum. Compacting the soil at different magnitudes of vacuum will give an indication of the effects of vacuum on lunar soil compactability. Then, cyclic loading, causing compression of the initial specimen, will be applied in a specially designed chamber using an MTS test frame. The experimental results will be plotted in terms of relations between initial density, initial vacuum, and number of loading cycles.

The material characteristics of the compacted samples (stress-strain response, angle of internal friction, and "apparent" cohesion) will be evaluated to assess the deformation and strength capabilities of the resulting compacted specimens.

Indeed, application of only compression cycles may not be able to provide the required deformation-strength characteristics for (all) construction objectives, and additional research to include other factors such as use of heat and chemicals would then be considered in subsequent research. This initial research would, however, provide the limit of compaction that can be achieved with cycles of compression without the use of water.

Results to Date

Samples of lunar soil simulant in grain sizes from 2 millimeters to less than 75 microns have been produced by crushing terrestrial basalt rocks. Approximately 0.25 cubic foot of lunar soil simulant, 30 percent of which is ultra-refined, is available for testing purposes.

A cylindrical vacuum chamber 15.0 inches high by 3 inches inside diameter has been machined from a single block of aluminum; design and fabrication of this device are supported by a grant from the Small Grants Program of the University of Arizona. The chamber is equipped with a ram-piston assembly to provide a means of loading the sample and is lined with Teflon to prevent cold-welding of the soil grains to the aluminum. Two ports in the chamber allow application of vacuum for both the top and bottom of the soil sample. Pressure is measured by a digital vacuum gauge with two Pirani PG-3 sensors attached to the chamber. The system is attached to a mechanical roughing pump and a diffusion-type vaccum pump capable of reducing the chamber pressure to 10 torr. Cyclic load is applied using an MTS hydraulic testing device which allows variation in load, cycle duration, and number of cycles and can automatically measure the displacement of the sample during loading.

Planned Research During the Next Year

A pilot series of tests will first be performed to establish the maximum compaction that can be achieved under different initial vacuums and density for a specimen of given initial height.

Then, a series of tests will be performed with three to four values of initial vacuum (V_0) and density (ρ_0). For each, the specimen will be subjected to cycles of compression loading. The results will be plotted in terms of variation of density with number of load cycles (N) for each V_0 and ρ_0. These results will be used to develop nondimensional relations between changing density as affected by V_0, ρ_o, and N.

A modified test device will be developed so that the compacted specimen can be tested with increasing axial stress, σ_1, (near) unconfined conditions, i.e., zero confining pressure σ_3 and different values of σ_3. The results will provide stress-strain relations in terms of $\sigma_1 - \sigma_3$ vs. ϵ_1 (axial stress). The deformation moduli and the strength parameters (angle of friction ϕ and cohesion C) can then be found from these stress-strain curves.

The above information will allow evaluation of the deformation-strength characteristics of the compacted specimens and the range of loading due to construction that such material is able to withstand.

It is felt that the above approach may not lead to materials with strengths required for (high) loads that may arise in common construction. Hence, the second phase of research would involve the use of factors such as heat and chemicals in addition to the cyclic compression loading. Acquisition of a furnace for this purpose is being considered at this time.

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III. SYSTEMS OPTIMIZATION