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GEOTECHNICAL ENGINEERING ON THE MOON; W. David Carrier, III and James K. Mitchell, Bechtel, Inc. and University of California, Berkeley.

Some of the geotechnical engineering considerations in large-scale operations on the moon are discussed in this paper. Constructing and operating a large base on the lunar surface entails special problems as well as special advantages not present on earth. Considerable soils data and experience were obtained from the Surveyor and Apollo programs which can now be applied to the design of future bases on the moon. Topics of particular importance are discussed below.

Insulation

It will be necessary to make use of the lunar soil as a construction material. It is very likely that lunar structures will be placed in shallow cuts and then covered over with lunar soil. Self-supporting, inflatable structures may be used. One to two meters of lunar soil cover will provide adequate insulation against thermal extremes, radiation, and micrometeorite impact. The soil could probably be placed in a loose condition and would have a density of about 1 g/cm^3. Even if it were compacted, the density would be less than 2 g/cm^3, and a two-meter layer would impose a stress of less than 7 kPa (1 psi), which would be considerably less than the internal atmospheric pressure. Loose soil could be placed on slopes of 2 horizontal to 1 vertical. The thermal conductivity of this insulating layer would be about 1 to 2x10^{-4} Watt/cm-K^{o} (1). Heating system design for the structure would be simplified due to the constant, albeit cold, temperature of about -20^{o}C at 1 to 2 m below the lunar surfaces (1) in contrast to the requirements for an above-ground structure.

Housekeeping

The lunar surface is dirty. The soil is a silty sand with a median particle size by weight of about 70 microns. Dust adheres to almost everything and will tend to migrate everywhere. Housekeeping will be a constant and frustrating activity, necessitating special brushes, vacuum cleaners, brooms, filters, air-locks, etc.

Soil Stabilization

Vehicular traffic will churn up, rut, and scatter the lunar soil. Permanent spacecraft landing pads will be an intermittent source of destructive high-velocity dust. In these areas, it will be necessary to stabilize the ground surface. Chemicals, such as polyurethanes and resins, could be sprayed, injected into the lunar soil, or mixed in place and rolled to produce a smooth, tight, compacted surface. Haul roads for mining operations will have to be similarly stabilized.

Separation of Soil Particles

Because of the small particle size and cohesiveness of the lunar soil, as well as the low gravity field, mechanical separation would be an extremely inefficient operation on the lunar surface, except for the coarsest particles (>1 cm), which make up less than 1% of the soil. Other methods, perhaps electrostatic, will have to be developed if separation is necessary for some potential industrial process.

Excavation

Excavation of the lunar soil will be very easy. Bulldozers will be used to move small amounts of soil for constructing bases. Large-scale mining will be performed either with drag lines or bottom scrapers. Large-scale transport of soil will be by bottom scraper, dump truck, or perhaps conveyor. Vehicles should be designed to operate at a wheel bearing pressure of approximately 7 kPa which will result in approximately 1 cm settlement in undisturbed soil. The power requirements will depend primarily on the design load, velocity, and climb characteristics of the vehicle. Thus, if it is desired to have a vehicle with a gross lunar weight of 100 kN that will negotiate a 10% grade at 20 kph, the required power would be approximately 60 to 70 kW (80 to 90 HP), including an allowance of 5 to 10% needed to overcome the rolling resistance due to the soil.

Deep Drilling

If large-scale mining or deep storage is contemplated, then much deeper drill holes will be necessary than the 3 m depths attained in the Apollo program. The drill holes would be used to establish the depth of easily excavatable soil as well as the chemical and mineralogical properties of the deeper soil and rock. It should be emphasized that the geophysical methods used to date (such as active seismic, traverse gravimeter, and surface electrical properties) have not provided unequivocal information on the depth of the soil to rock. Unfortunately, the data can be interpreted in different ways. Direct evidence from deep drill holes in conjunction with geophysical data will be essential in studies comparing open-pit mining with strip mining.

Slope Stability

The lunar soil has typical shear strength parameters of: cohesion = 1 kN/m^2; friction angle = 35^o. With a density of 2 g/cm^3, the soil will be stable in a vertical cut over 2 m deep. However, it would be prudent to limit vertical cuts to 1.5 m, as is required by OSHA on earth. Very deep cuts, as in an open-pit mine, would be cut in a series of benches, with the over-all slope controlled by the friction angle. Such an excavation could be constructed at 1-3/4 or 2 horizontal to 1 vertical with the usual factor of safety of 1.25.

Settlement

Most structures on the lunar surface will be very lightly loaded and flexible and will not be adversely affected by settlement. The modulus of subgrade reaction for the lunar surface is typically 1000 $kN/m^2/m$, based on Astronaut bootprints. A footing applying a pressure of 10 kN/m^2 would normally settle approximately 1 cm, but could settle as much as 10 cm or as little as 0.1 cm. Where differential settlements are important, as in an observatory, it would be necessary in the absence of specific site data, to design the footings assuming a lower modulus. Based on available density distributions, if it were necessary to limit the settlement to less than 1 cm with a probability of 95%, a modulus of 200 $kN/m^2/m$ would be used and the footing pressure would be reduced to 2 kN/m^2. Other means are also available to minimize the settlements; e.g., surface compaction, excavation to place the footing on firmer soil, and chemical stabilization.

Waste Disposal and Storage

Because of its relatively fine gradation, the fluid conductivity of the lunar soil would be too low ($<1 \times 10^{-5}$ cm/sec) to permit its use as a drain field for liquid waste. On the other hand, because of the ease of excavation and the excellent insulating properties of the lunar soil, underground chambers for storage of cryogenic fluids should be feasible. The lining of such chambers could be accomplished using polyurethanes.

Conclusion

Much specific knowledge of lunar soils is already available relative to their use for civil engineering on the moon. A major unknown is the nature of the materials deeper than 3m. Deep drill holes will be needed in the early stages of further lunar exploration and development.

Reference

(1) Langseth et al. (1973), Apollo 17 Preliminary Science Report, NASA SP-330, pp. 9-1 to 9-24.

Bibliography

Carrier, et al. (1973), Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 99, pp. 813-832.

Carrier, et al. (1973), Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 99, pp. 979-996.

Mitchell, et al. (1972), Apollo 16 Preliminary Science Report, NASA SP-315, pp. 8-1 to 8-29.

Mitchell, et al. (1974), Final Report, Contract NAS 9-11266, Space Sciences Lab, Series 15, Issue 7, University of California, Berkeley.