REGOLITH-STRUCTURE MODELING

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Early lunar missions have provided a basic understanding of the physical and strength properties of lunar regolith, which have been shown to differ from those of dry terrestrial granular soils. Lunar regolith is predominantly a fine sand of which nearly 40% can be characterized as silt with a particle size smaller than 100 micrometers. The top 10 to 20 cm of the regolith can be characterized as being in a loose to medium-loose state. The density of the regolith, however, rapidly increases below a depth of 20 cm. The highly irregular and angular shapes of the regolith particles tend to interlock and create relatively strong mechanical bonds that give the particulate mass substantial cohesive properties and smaller amounts of tensile strength properties. In addition, the friction angle of lunar regolith at medium to high densities is quite high and often exceeds 55 degrees.

These known properties of lunar regolith have been matched in a terrestrially-manufactured analog known as Minnesota Lunar Simulant. A variety of experiments have been conducted using this simulant to both verify existing information and generate new information on the physical and constitutive properties of lunar regolith. These experiments include maximum and minimum density determinations, specific mass of solids, grain-size distribution, conventional triaxial compression and extension, isotropic compression, one-dimensional compression, direct shear and direct tension. Direct shear experiments have been conducted under atmospheric and vacuum conditions. Results of the physical and strength experiments compare closely to results obtained from lunar missions. Results of simulant strength experiments performed in vacuum indicated no observable difference from results obtained in air.

A testbed currently under study is one involving a regolith shield covering a first-generation human habitat module. We understand that regolith in depths ranging from 3 to 5 meters is required for radiation shielding for habitation and workspace. In our study the habitat module is treated as a rigid cylindrical tube with a smooth exterior. By making the cylinder rigid, we have reduced a complex interaction problem to a situation where we can consider the support regolith and the shielding regolith as behaving independently of the structural properties of the cylindrical structure. Medium-dense lunar simulant has been placed around a scaled model of the habitat module to provide a radiation shield. This embankment-type shield was constructed in relatively thin but fine layers by compacting, by mechanical vibratory means, layer upon layer of simulant placed adjacent to the horizontally-aligned cylinder. The slope angles were constructed at 55 degrees.

The model described above has been studied in a geotechnical centrifuge, which allows for the scaling of model dimensions to prototype dimensions by increasing the acceleration of gravity on the model. The deformation response can be scaled up to prototype dimensions to provide an assessment of the deformation patterns of the lunar structure. The actual process of local and/or global growth of instabilities or skip planes can also be observed.

Finite element techniques can be used to predict the response of the model in the geotechnical centrifuge, in order to validate the utility of the finite element analysis technique. The finite element model uses a plasticity-based constitutive model to describe the regolith material properties. This constitutive model has been calibrated (using the experiments described in the second paragraph above). The validated finite element model can then be used with a high degree of confidence to predict the response of other types of slope configurations with more complex geometries. These results will be of help to designers involved in cost-benefit studies of constructed lunar facilities.

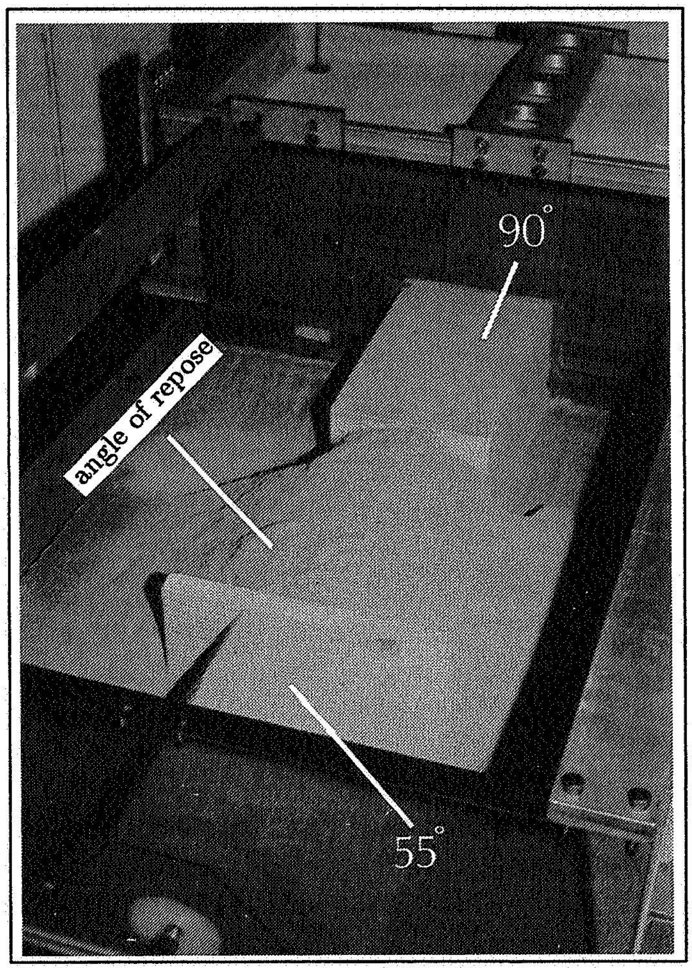

Fig 8.1 Demonstration models of 90°, 55° and angle of repose slopes for a regolith structure

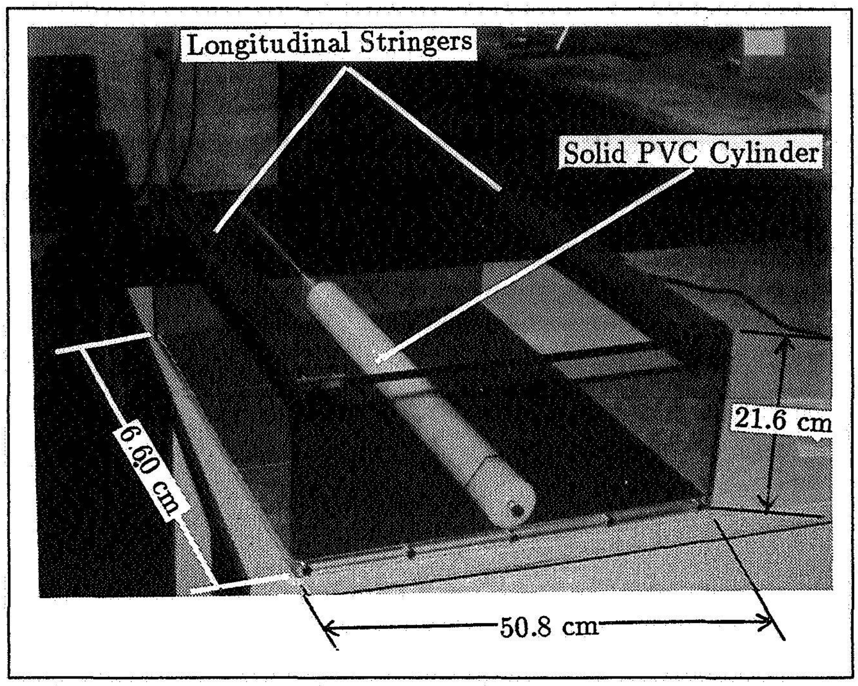

Fig 8.2 Centrifuge model slope container for a regolith structure

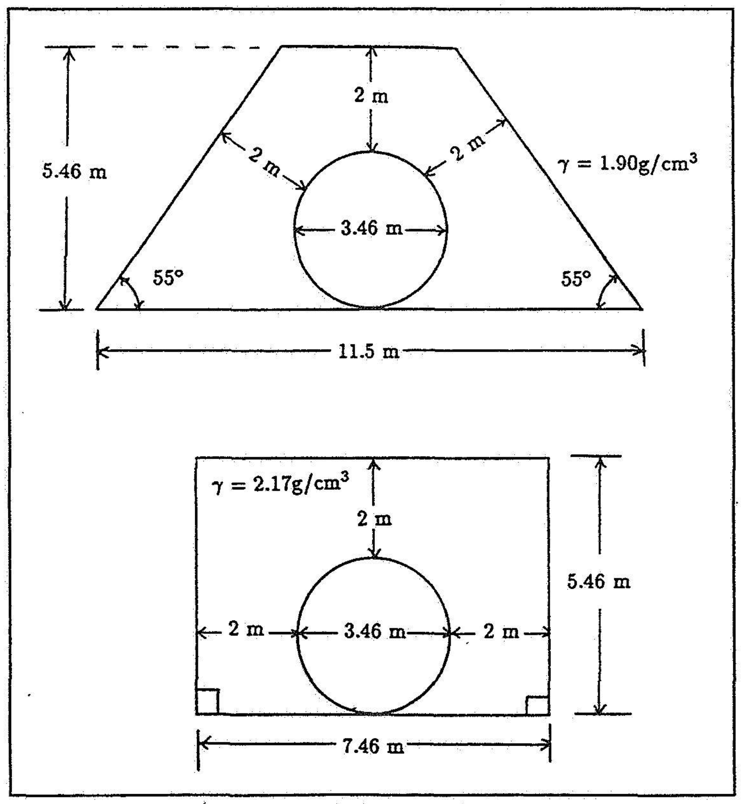

Fig 8.3 Lunar prototype H.H.M. dimensions

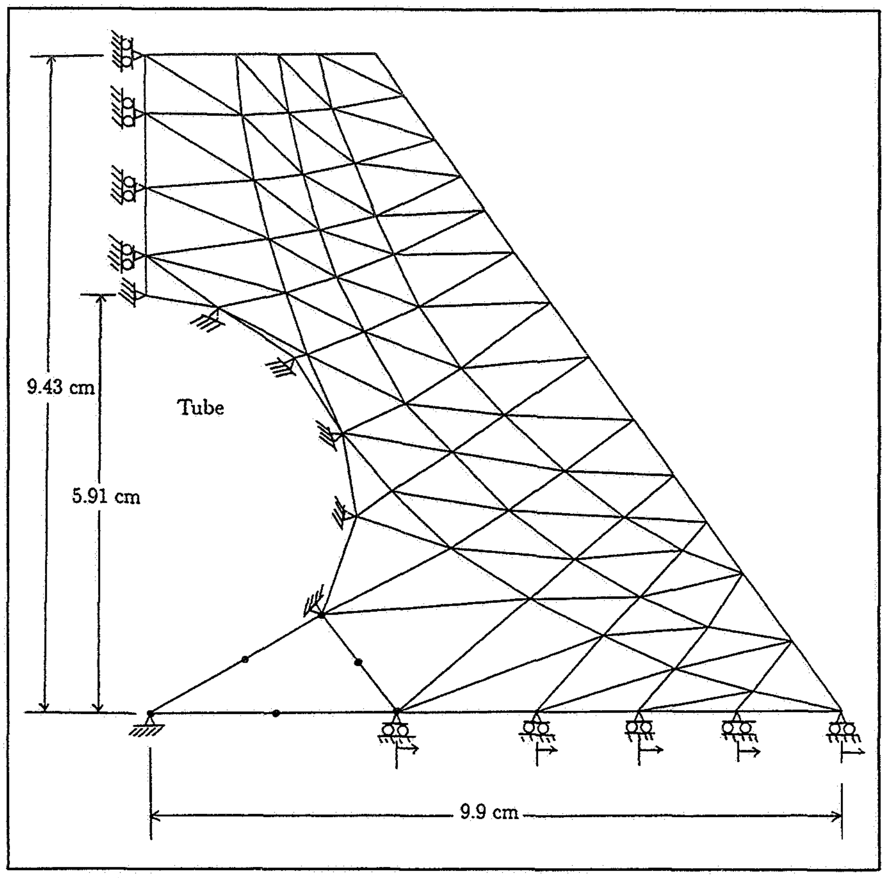

Fig 8.4 Finite-element model of the lunar habitat

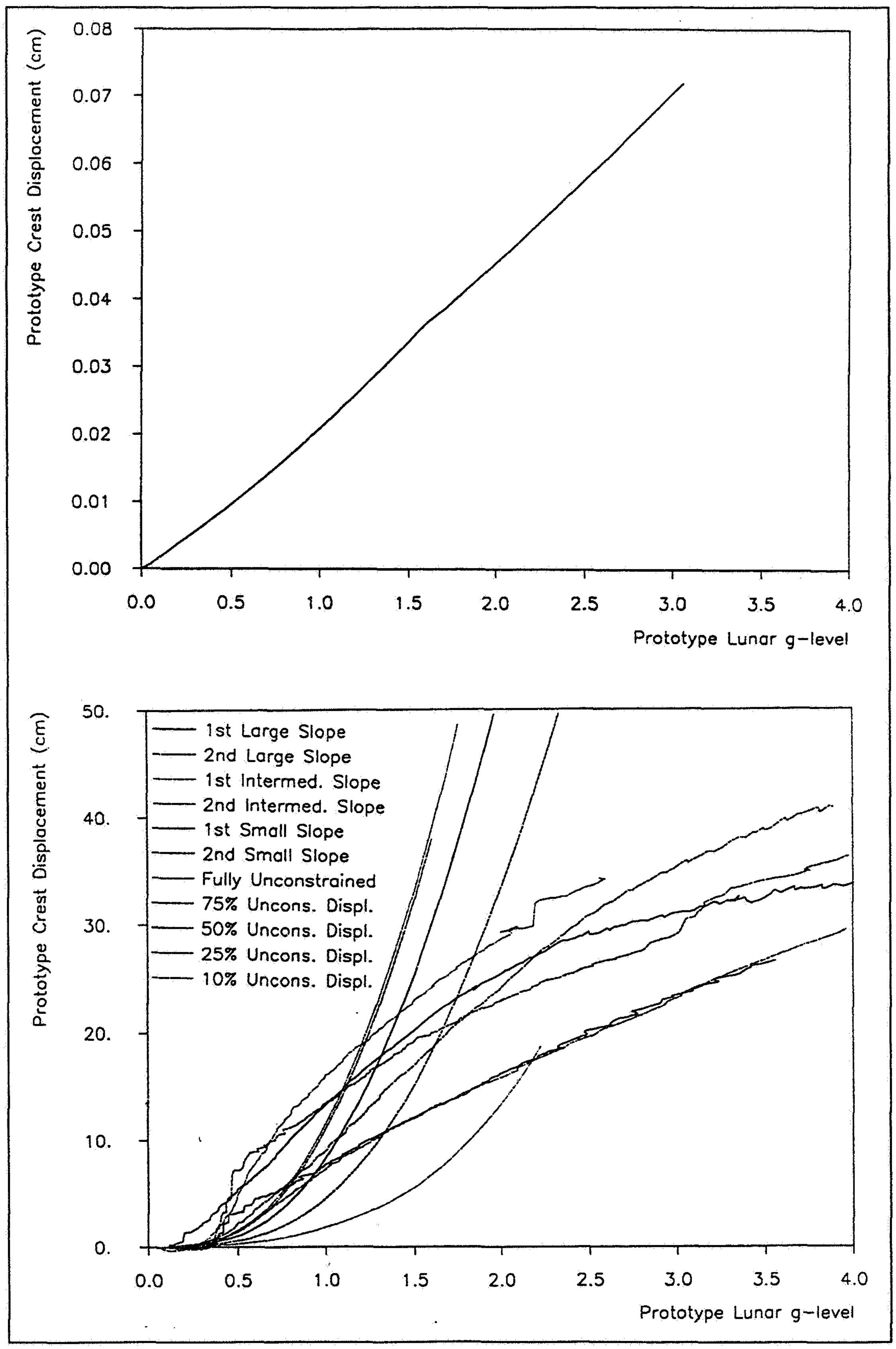

Fig 8.5 Influence of displacement condition of bottom nodes