Brick by Brick: Study of Modular Block Construction for Lunar Habitats

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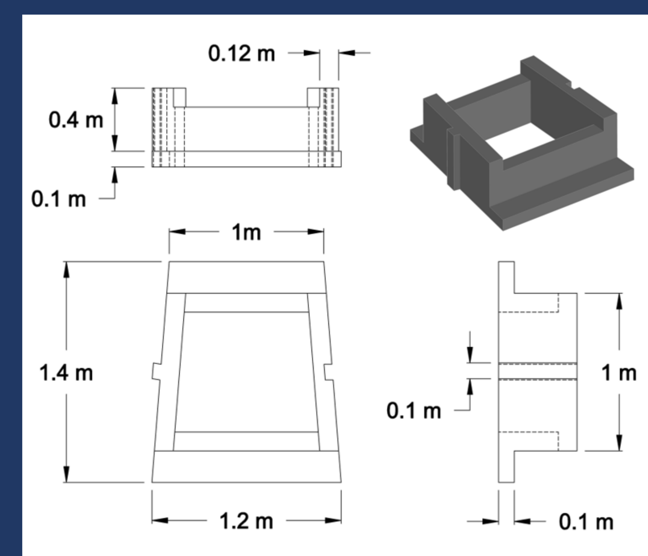
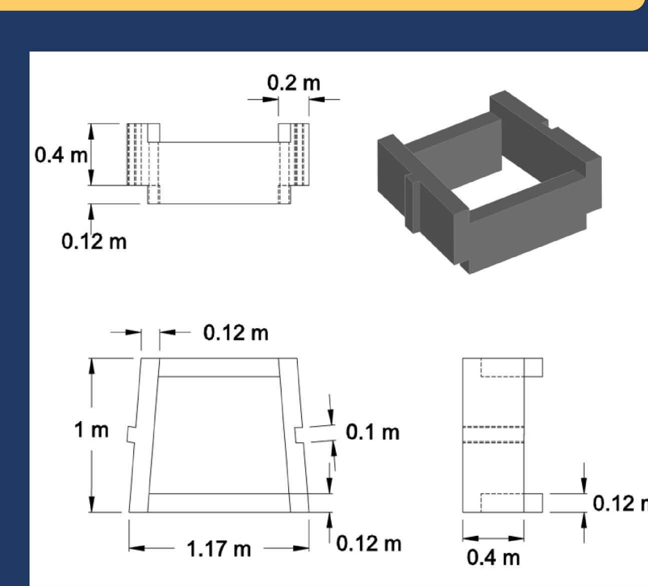
GENERAL IDEA AND GOALS

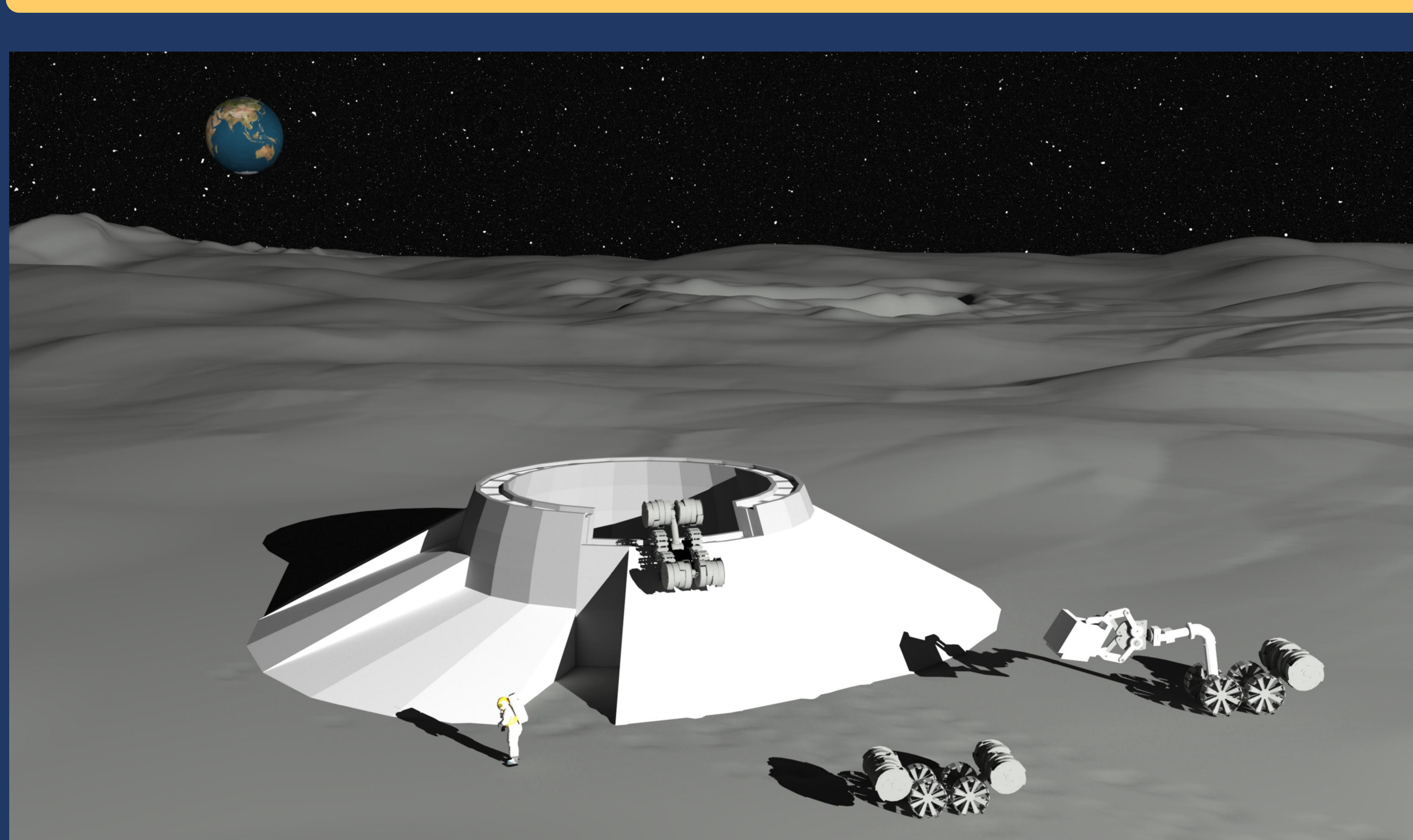
The goals implemented in the development of modular blocks approach for future lunar infrastructure include the application of ISRU due to the high cost of space transportation, minimal and already developed robotic construction equipment, practicality in the on-site assembly of the lunar infrastructure, practicality in inspections and maintenance of the structural members, and variation in infrastructure use [1]. Previously published trader study of the existing and novel lunar habitat concepts [2] has proven the feasibility of the modular block construction approach, showing potential for a sustainable design, minimizing the on-site human construction, and use of already developed technology.

MODULAR BLOCK DIMENSIONS





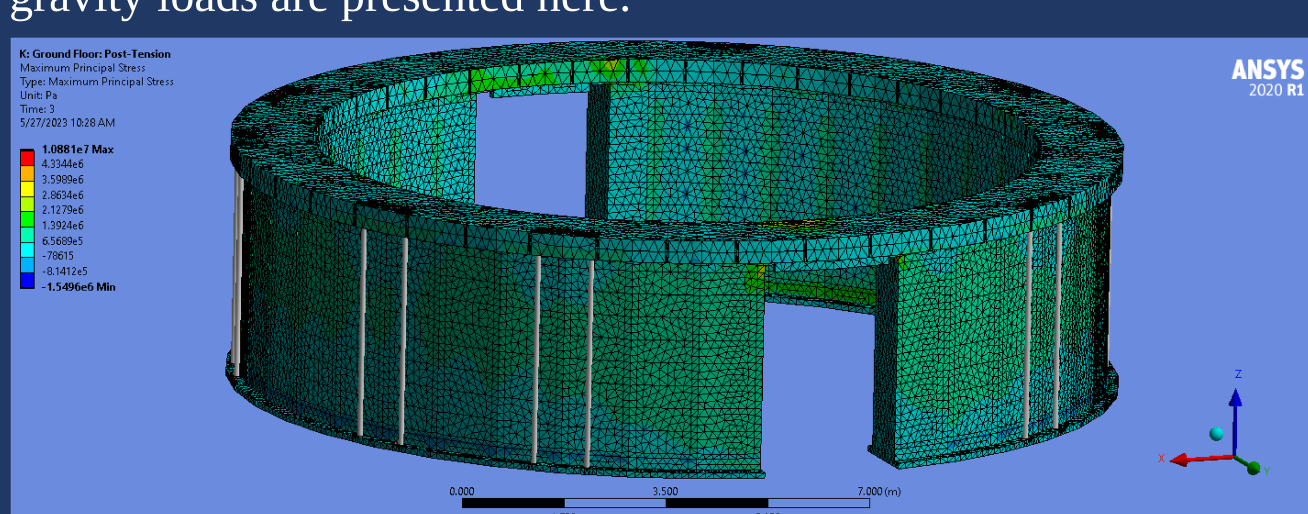
CONSTRUCTABILITY

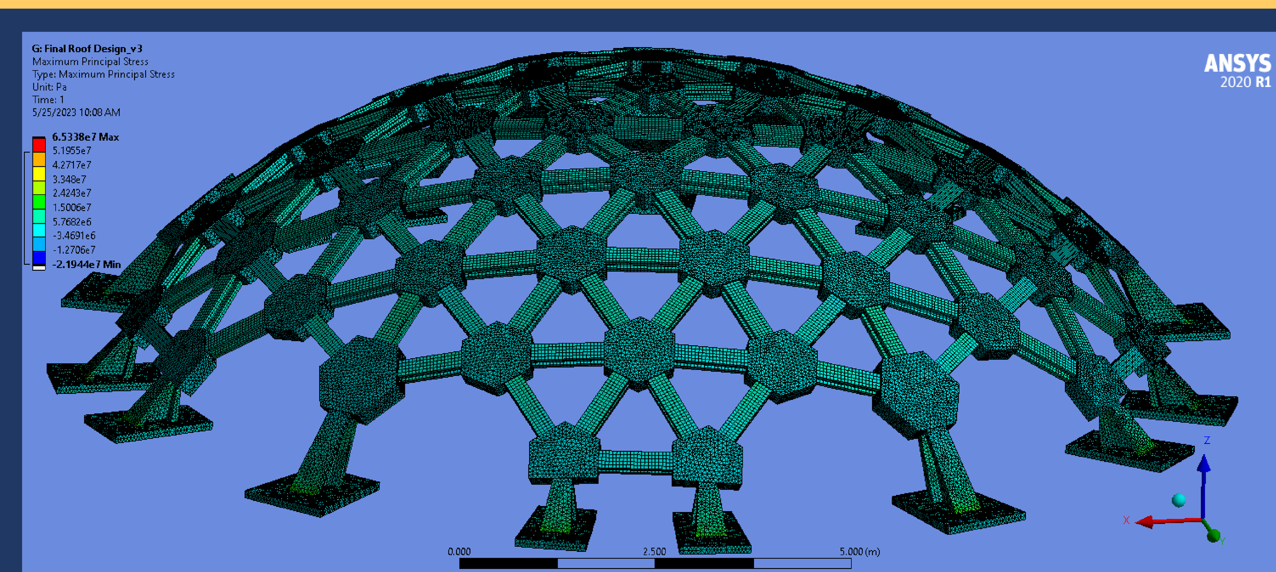


The goal is to provide a relatively simple construction process with minimal on-site assistance from the astronauts, while having durable and multipurpose construction and assembly equipment. The small regolith mobile rovers are recommended for the modular block assembly, possessing potential applicability of the already-existing technology, like RASSOR [3]. The RASSORs would place one layer of the blocks and then fill the cavities with the loose lunar regolith to achieve an appropriate isolated environment. Afterward, RASSORs will construct a berm around the assembled blocks, onto which they would climb and place the next layer of the modular blocks and fill in the cavities. The process will be repeated until all the block layers are in place, while the regolith-based berm will be left in place to provide shielding from the harsh lunar environment.

STRUCTURAL ANALYSIS

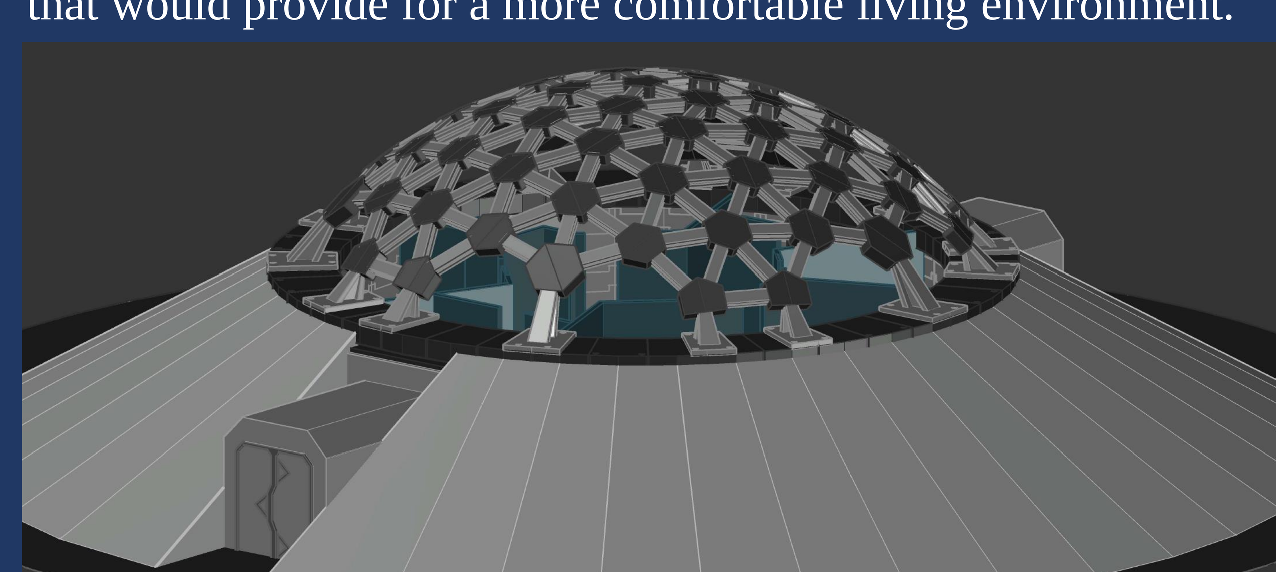
This study incorporates the following parameters as part of the FEA checks: yielding of any metal structural element is avoided; assumed lunar concrete has no yield strength; yielding design Factor of Safety (FOS) was taken as 2.0 for the metal structural parts; ultimate design FOS was taken as 2.0 for the FEA of all habitat elements, with the value of margin to be 1.5 or above; the margin for ultimate design FOS of 3.0 was aimed to be above zero. Three different types of FEA are to be run to reach the appropriate structural integrity, including pressure + gravity loads, meteorite impact load and thermal gradient. Only pressure + gravity loads are presented here.



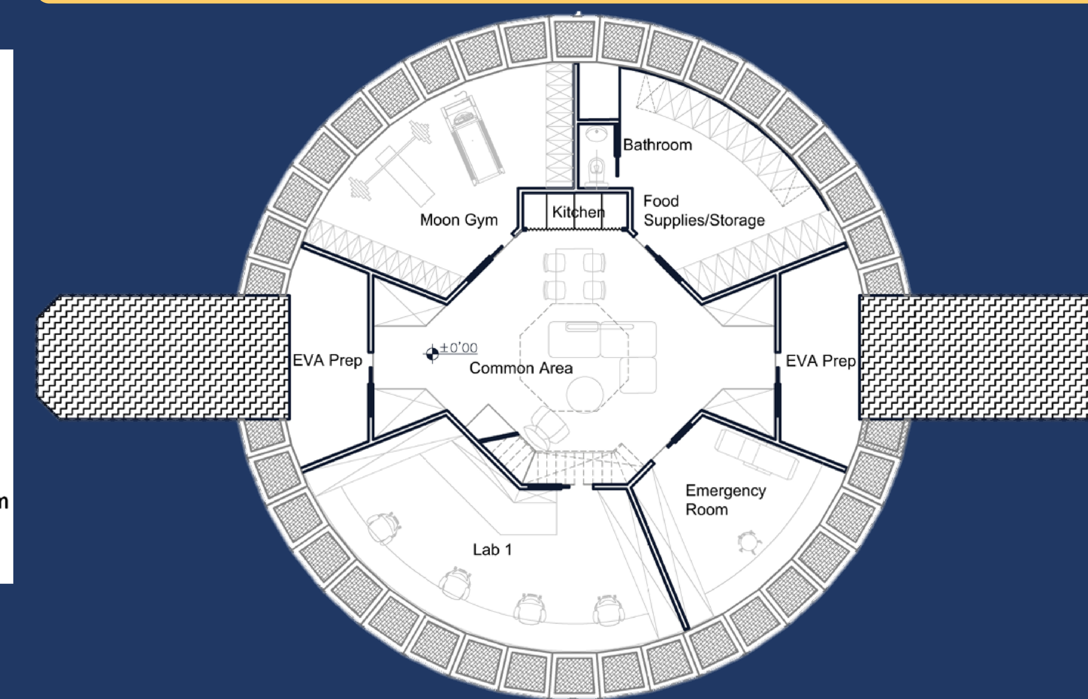


The pressure + gravity load analysis consists of two steps. The first step includes the analysis of the roof system, optimizing the individual elements and material properties. The final design, shown above, includes link elements ranging from one hex element to another, assumed to be made from ISRU-obtained aluminum alloy. The hex elements are designed to be made either out of more advanced lunar polymer concrete or aluminum alloy. The gaps in between are to be filled with titanium or aluminum alloy panels, with several glass elements that would provide for a more comfortable living environment.

The second analysis consists of understanding the structural limitations of the ground floor system. It is to be made from 10 layers of lunar polymer concrete modular blocks, 40 titanium alloy connection blocks that are designed to transfer stresses from the roof system through bolts, with additional 16 post-tension rods providing additional support against the internal pressure and gravity loads. The boundary condition between the modular blocks was assumed to be bound. The margins were proven to be within acceptable limits, and the analysis was continued with modeling of the meteorite impacts and thermal gradients.

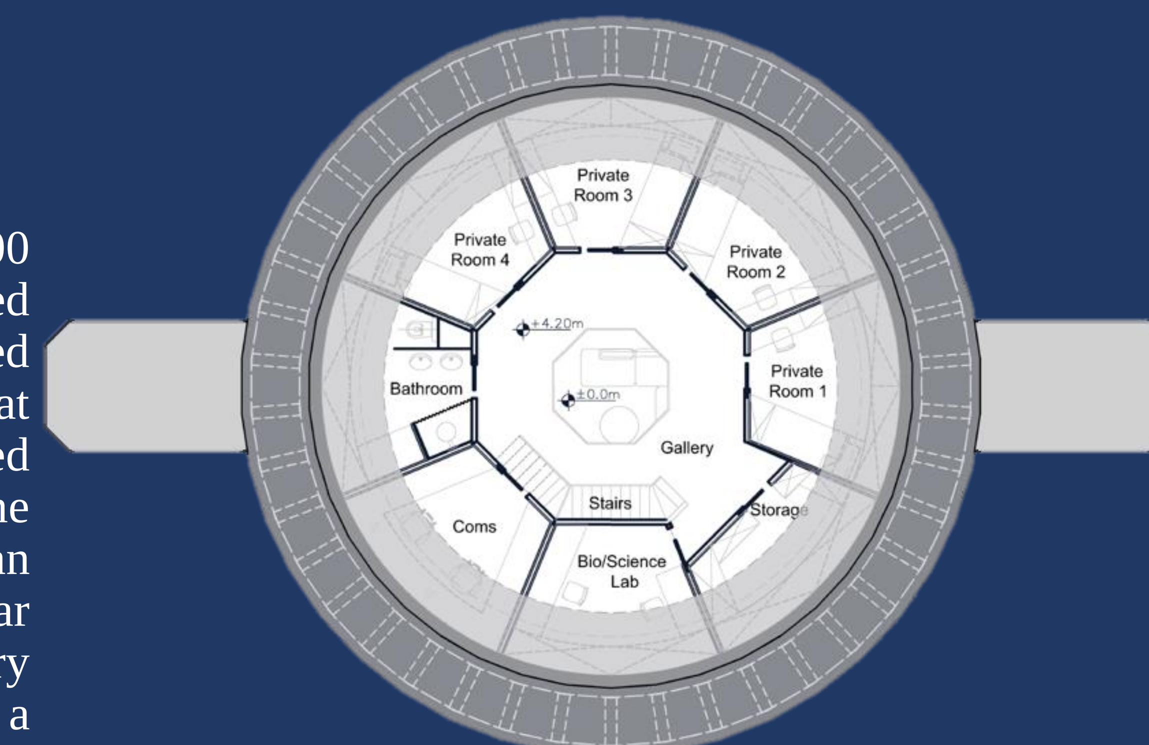


NET HABITABLE VOLUME AND FLOOR PLAN

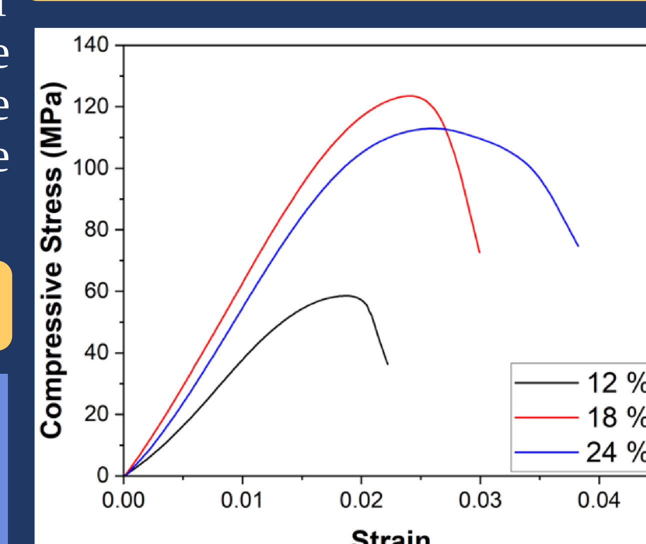


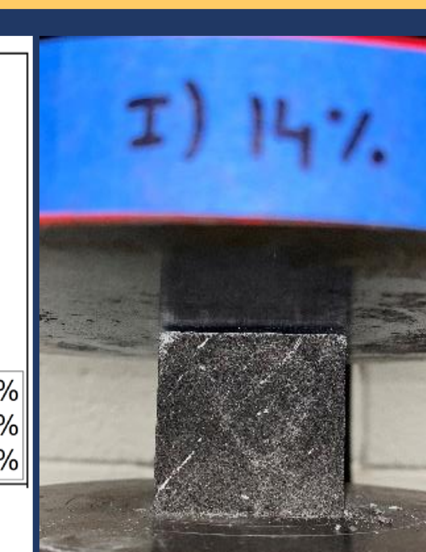
Even though several research studies have been conducted on the net habitable volume (NHV) requirements for off-Earth habitats, further groundwork needs to be placed, incorporating analog habitats as a testing ground for the mitigation of psychological and non-psychological stressors. Additionally, the impact of the reduced gravity will need to be accounted for when designing taller ceiling.

For this research, an approximate volume of 100 m^3/crew member was taken, with the assumed ceiling height of 3.5 meters, based on the limited amount of data found. With the assumption that approximately 60% of the total pressurized volume is to represent the NHV, the total volume is estimated to be around 640 m^3. To arrive at an exact volume and layout design of the lunar habitat is a complex and multidisciplinary problem, and it is identified as a process, not a simple specification.

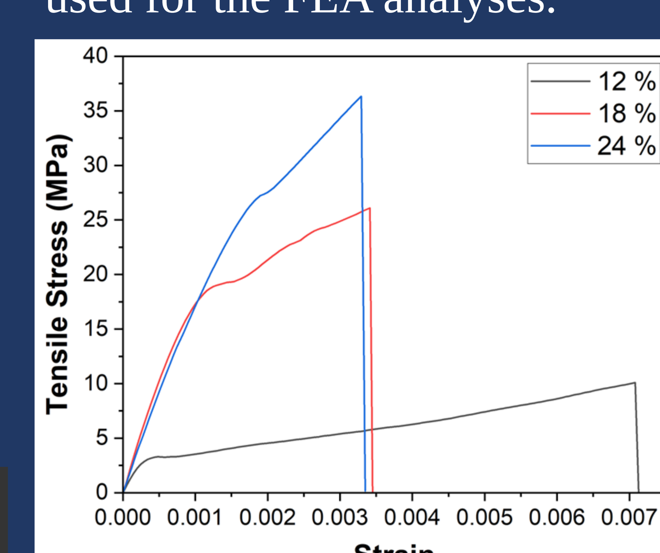


CONSTRUCTION MATERIAL





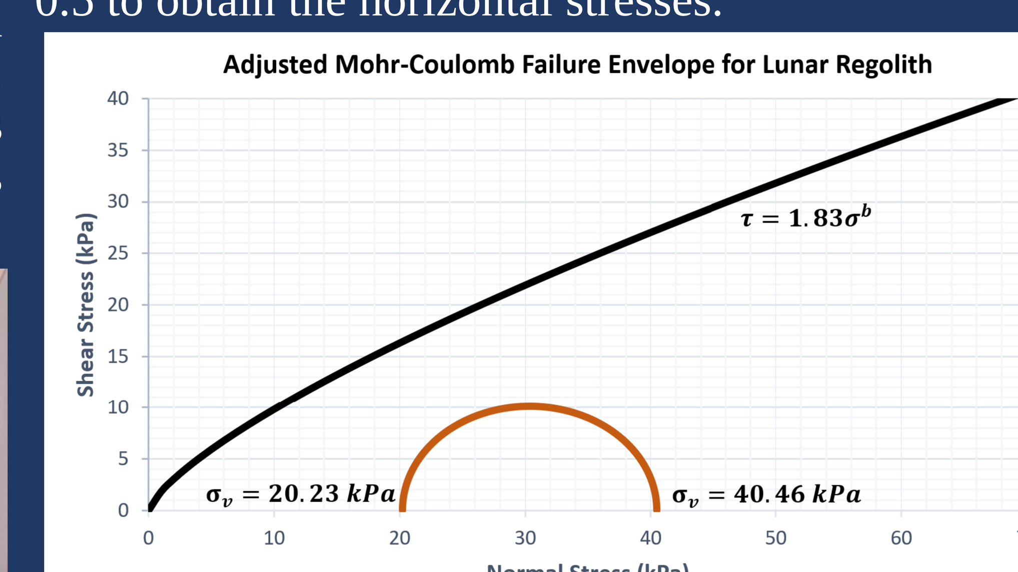
A trade study of potential materials that could be used for the initial lunar infrastructure has been conducted, identifying 9 categories. Lunar polymer concrete was chosen as the construction material due to its simple use, compatibility with the lunar environmental conditions, and sufficient material properties. Destructive and non-destructive testing was conducted to obtain the initial material properties used for the FEA analyses.



Samples containing 12% to 24% of the polymer by volume were tested. 18% of the polymer by volume has shown the best results, possessing compressive strength and Young's modulus of 123.76 MPa and 4.98 GPa, and tensile strength and Young's modulus of 27.52 MPa and 21.58 GPa, respectively. Both the destructive and non-destructive testing were in line, providing very similar results and proving thier efficiency.

SOIL AND FOUNDATION

The loads imposed by the lunar surface structure onto the soil beneath are considered and are to be transferred to the soil through surface preparation and foundation design. A simple approach for the foundation design has been taken, choosing a mat foundation to support the intended lunar base structure. Considering a circular shape of the mat foundation, with a thickness of 1 m, and density associated with a compacted/sintered regolith, the influence factor was calculated to be 0.9997573 using Boussinesq's equation. Following the approximated total weight calculations, the vertical stresses that are to be imposed on the soil were estimated. The lateral stress coefficient was taken as 0.5 to obtain the horizontal stresses.



References:

[1] Caluk, Nerma, and Atorod Azizinamini. "Introduction to the concept of modular blocks for lunar infrastructure." *Acta Astronautica* 207 (2023): 153-166.

[2] N. Caluk and A. Azizinamini, "A summary of technical requirements, environmental factors and loading for lunar infrastructure," in *Earth and Space 2022: The 18th Biennial International Conference on Engineering, Science, Construction, and Operations in Challenging Environments*, 2022.

[3] R. P. Mueller, R. E. Cox, T. Ebert, J. D. Smith, J. M. Schuler, and A. J. Nick, "Regolith Advanced Surface Systems Operations Robot (RASSOR)," in *IEEE Aerospace Conference Proceedings*, 2013. doi: 10.1109/AERO.2013.6497341.