Analysis and Design of Lunar Structures under Extreme Diurnal Temperature Variations and Hypervelocity Meteoroid Impacts

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Abstract:

The ongoing worldwide resurgence of interest in lunar exploration includes significant plan for establishing civil engineering infrastructure for long term human presence. Lunar base structures must be capable of withstanding extreme environmental challenges such as low gravity, hard vacuum, hazardous radiation, large temperature fluctuations, moonquakes, and meteoroid impacts. This seminar talk will begin with introducing the extreme environmental conditions that exist on the Moon and the engineering and construction challenges they pose. It will then present recent advances in developing physics-based methodologies for analysis and design of lunar structures against extreme lunar diurnal temperature variations and hypervelocity meteoroid impacts. First, a comprehensive analysis of the thermo-mechanical response of a dome-shaped lunar habitat will be presented considering with and without regolith (lunar soil) shielding, and incorporating various heat sources, including direct solar radiation and lunar albedo, as well as heat sinks, such as non-blackbody radiation and habitat albedo. The results show that the use of regolith cover significantly reduces the diurnal temperature fluctuations at the interior surface of the habitat wall. The study also involves stress and deflection analysis, which reveals that thermal loading may be the primary factor affecting the design of the structures on the Moon. Next, a shock physics-based analytical methodology will be discussed for hypervelocity meteoroid impact-resistant design of lunar structures. The initial shock pressure due to meteoroid impact is determined using the impedance matching technique. Shock wave expansion and shock pressure attenuation are also analytically modeled to obtain a first-order estimate of the regolith cover thickness required for a desired protection of the underlying structural layer. Practical application is illustrated through a parametric analysis that considers a range of meteoroid impact scenarios. The proposed analytical method should provide an important tool for engineering design of hypervelocity impact-resistant lunar structures. Finally, for the general interest of the audience, a few minutes will be spent introducing the ASCE Aerospace Division and its initiative on developing the Lunar Infrastructure Engineering guidelines and its upcoming Earth & Space 2024 Conference.

Bio:

Ramesh B. Malla, a Professor of Structural Engineering and Applied Mechanics at UConn, has over 42 years of experience in teaching, research, and industry, with more than 38 years at UConn. He worked as a structural engineer at United Engineers & Constructors, Inc. and held positions at NASA Lewis Research Center and Hamilton Sundstrand Space Systems International, Inc. He served as Founding UConn Campus Director of NASA/Connecticut Space Grant Consortium and Founding Institutional PI/Lead for NASA STRI/Resilient Extraterrestrial Habitats Institute. Since 2018, he has been Institutional Lead of U.S.DOT Region 1 (New England) UTC -Transportation Infrastructure Durability Center.

His expertise includes structural engineering, applied mechanics, dynamics & vibrations of structures, and finite element analysis, focusing on terrestrial and extraterrestrial structures. He has authored/co-authored over 160 technical publications and held leadership roles in various conferences and committees. Currently, he chairs the Space Engineering and Construction Technical Committee of ASCE Aerospace Division and serves as Honorary Chair of ASCE Earth & Space 2024 Conference.

Monday, March 4th, 2024   4:00 – 5:20 p.m.

1310 Yeh Student Center