OVERVIEW OF THE ASCE ASD SPACE ENGINEERING AND CONSTRUCTION TECHNICAL COMMITTEE – LUNAR INFRASTRUCTURE ENGINEERING, DESIGN, ANALYSIS, AND CONSTRUCTION GUIDELINES: LUNAR STRUCTURAL LOADS SUBGROUP. I. E. Jehn[1], S. Pfund[2], N. Caluk[3], and R. B. Malla[4]; [1]Colorado School of Mines (1310 Maple St., GRL 234, Golden, CO 80401, ijehn@mines.edu), [2]LERA Consulting Structural Engineers (40 Wall Street, Floor 23, New York, New York 10005, stephen.pfund@lera.com), [3]Florida International University (10555 West Flagler Street, EC 3678, Miami, FL 33174, ncaluk@fiu.edu), [4]University of Connecticut (261 Glenbrook Road, Storrs, CT 06269, Ramesh.Malla@uconn.edu)

Introduction: At the present day, there are no building codes or standards for the design of structures and infrastructure facilities on the Moon. The American Society of Civil Engineers (ASCE) Aerospace Division (ASD) Space Engineering, and Construction (SEC) Technical Committee has initiated the development of the Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines. Five subgroups have been working on separate components of the lunar infrastructure guidelines, including Construction & Materials; Structural Design Loads; Environmental Considerations; Geotechnical & Foundation; and Structures Design, Analysis, and Architecture. The information provided in this abstract is focused on the Structural Desing Loads subgroup, which has set out to develop and define a preliminary set of tangible loading criteria for use in designing lunar buildings and infrastructure. This preliminary structural load criteria will be based on accepted terrestrial-based standards and design practices with appropriate modifications applicable to the lunar environment. This document is intended to provide a foundation for the development of future lunar structural design standards and building codes.

The objective of the paper/presentation is to provide an overview/update of the current work on the lunar loading criteria done by the Structural Design Subgroup and to initiate discussion to receive comments from industry, government agencies, and academia to incorporate into the first draft of the document.

Terrestrial Design Standards: On Earth, civil engineers, geotechnical engineers, structural engineers, architects, and other building professionals rely on building codes and referenced design standards to define the minimum requirements for design. These documents include definitions of structural loads, which are essential to any infrastructure or building design practice. An integral part of building codes in the United States, ASCE 7, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures" [1], is a nationally recognized standard that describes the means for determining design structural loads and their combinations for general structural design. This document is updated and released every six years and is ASCE's most widely used professional standard to enable engineers' commitment to protect the health, safety, and welfare of the public.

Earth vs Moon Design Environment: Environmental conditions are key to structural design considerations. In a comparison of natural environments, there are some similarities between the Moon and Earth. Seismic activity is experienced on the lunar surface, generated by thermal changes, tidal influences from Earth, meteoroid impacts, and underground magma pressures influencing lunar stagnant lid plates [11, 17, 18]. Also, due to the Moon's proximity to Earth and its location in the solar system, there is a similar exposure to heat flux and radiation produced by the Sun [7]. Additionally, the Moon rotates around a titled axis producing both daily and yearly surface temperature fluctuations like on Earth [22].

However, there are some major and drastic environmental differences between the Earth and the Moon that should be considered for any lunar structures/infrastructure design and construction [12, 13]. One is the difference in gravity; the moon's gravity is one-sixth of that of Earth. Next, the Moon does not have an atmosphere. Instead, trace noble gases and moderately volatile elements are located near the lunar surface. This is called an exosphere, with a pressure of approximately $3x10^{-10}$ Pa, which is generally considered a vacuum environment [16]. Third, the diurnal (day-night) cycle is very long. One day on the Moon is approximately 14 days long on Earth. Finally, with this lack of atmosphere, there is no liquid water on the surface, and thus, no water weathering processes like on Earth.

The lack of lunar atmosphere increases the exposure of the surface to radiation and meteorite impacts [11, 21]. The lack of atmosphere, coupled with a long diurnal cycle, make the day-night temperature swing on the Moon extreme, and thermal loads are a dominant consideration for any structures/infrastructure design [15, 20]. Additionally, billions of years of exposure to high radiation and impactors have pulverized the surface crust into a highly cratered-dusty environment via impact gardening, which has produced a densified small particle-size regolith surface that will influence the design of any surface element [5].

Considering the relevant environmental characteristics of the Moon, and the similarities to the Earth, there are precedents in terrestrial structural design that can be used as a basis and modified to develop a tangible set of structural load criteria applicable to lunar-based design.

Lunar Application: Since ASCE 7 is widely recognized in the US and relied upon by engineers for determining loading criteria for designing buildings and other structures, the Structural Loads Subgroup is dedicated to the development of similar structural load criteria for lunar surface applications. The subgroup has already begun developing this criteria by engaging industry professionals in architecture, civil/structural/geotechnical engineering, and aerospace engineering, among others. Our group is actively investing in current research efforts and incorporating previous research into this document. A draft of the new lunar structural loading criteria is in progress and will be included as part of an overall "Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines" that will be published through the ASCE Space and Engineering and Construction Technical Committee.

Document Contents: A summary of loading criteria to be included in this document is listed below. Note that this is not an inclusive list, but selected items that would be of interest to attendees of the SRR conference.

- <u>Dead Loads (Static Loading)</u>: lunar gravity, vertical and lateral regolith forces, and regolith bearing.
- <u>Live Loads (Dynamic Loading)</u>: Roof loads, radiation shielding, human-induced loading, autonomous machinery loads, traffic loading, vibration effects, and artificial atmospheric pressures.
- <u>Rocket Plume Impingement</u>: vertical and horizontal pressure, rocket plume heat flux and temperatures, and acoustic effects.
- <u>Seismic Design Criteria</u>: acceleration parameters, design response spectrum, seismic design category, seismic load effect, and analysis procedures.
- <u>Meteorites, Micrometeorites, and Artificial Impactors</u>: impactor size and frequency, hypervelocity impact phenomena, impactor shielding systems, energy-impulse design procedure, and direct impacts.
- <u>Lunar Environmental Loads</u>: temperature fluctuations, thermal fatigue, cosmic and solar radiation, and lunar dust electrostatic effects.
- <u>Combination of Loads</u>: allowable stress design, and strength design.

Acknowledgments: First and foremost, the authors of this abstract would like to acknowledge the support from the ASCE Aerospace Division technical committee on Space Engineering and Construction (Chair: Ramesh B. Malla) for initiating the development of the Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines.

Additionally, the authors express their thanks to the following members of the Design Loads subgroup for their input and comments on this work: Peter Carrato, Bechtel (retired); Toni Curate, NASA Kennedy Space Center; Nathan Gelino, NASA, Kennedy Space Center, Swamp Works; Alexander Jablonski, Canadian Space Agency; Sudarshan Krishnan, University of Illinois at Urbana Champaign; Laurent Sibille, Southeastern University Research Association; Pooneh Maghoul, Polytechnique Montreal; Landolf Rhode-Barbarigos, University of Miami; Sachin Tripath, Univeriesity of Connecticut; Sushrut Vaidya, University of Connecticut.

References: [1] ASCE (2016) Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16) ASCE. [2] Akisheva, Y., and Gourinat, Y. (2021) Applied Sciences, 11(9), 3853. [3] Ali Khan, T. et al. (1988) Contract NAS9-17878. [4] Benaroya, H. and Bernold, L. (2008) Acta Astronautica, 62(4–5), 277–299. [5] Carrier, D., et al. (1991) Ch 9: Physical Properties of the Lunar Surface. Lunar sourcebook: A user's guide to the Moon. [6] Dickson, C. and Suermann, P. (2023) Earth and Space 2022 Conference, 199–206. [7] Eckart, P. et al. (2006) McGraw-Hill. [8] Eldred, K. M. and Jones, G. W. Jr. (1971) NASA SP 8072. [9] Evans, S. W. et al. (2006) Earth & Space 2006 Conference, 1–8. [10] Gelino, N. J. et al. (2021) Earth and Space 2021 Conference, 855–869. [11] Jablonski A. M. and Ogden K. A. (2008) J. Aerosp. Eng., 21, 72-90. [12] Malla, R.B. et al. (1995) J. of Aerospace Engineering, 8 (4), 189-195. [13] Malla, R. and Gionet, T. (2013) J. of Aerospace Engineering, 26 (4); pp 855-873. [14] Malla, R.B. and Brown, K. (2015) Acta As-tronautica, Vol. 107, 196-207 [15] Mehta, M. et al. (2013) AIAA Journal, 51(12), 2800–2818. [16] McSween, H., et al. (2019) Ch 12: Planetary Atmospheres, Oceans, and Ices. Planetary Geoscience. [17] Nunn, C. et al. (2020) *Space Science Reviews* (Vol. 216, Issue 5, pp. 1–39). [18] Nakamura, Y. et al. (1979) *Lunar and Planetary Science Conference*, 10th, 2299–2309. [19] Subedi, S., and Pradhananga, N. (2021) Earth and Space 2021 conference. [20] Tripathi, S. and Malla, R.B. (2023) Acta As-tronautica, vol. 204, 263-280. [21] Vaidya, S. and Malla, S. (2023) NASA/Lunar Surface Innovation Consortium (LSIC) Spring 2023 meeting; April. [22] Williams, J.-P. et al. (2017). Icarus, 283, 300–325.