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The first ever landing and experiments on the far side of Moon & Future geotechnical considerations

Premier atterrissage et essai du côté lointain de la lune & considérations géotechniques futures

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ABSTRACT: The success of the Chang' E 4 and Chang' E 5 missions marks a phased victory for China's lunar exploration project, which has attracted worldwide attention. Chongqing University is responsible for the research and development of biological equipment payload (BEP) in Chang' E 4 explorer. This paper describes the design and test of BEP, and introduces the germination and growth of organisms in the tank. The successful germination of cotton seeds marks the first time that human beings have cultivated crops on an alien planet. Chang' E 5 successfully sent rock and soil samples collected from the Moon back to the Earth. Research on the geological and geotechnical properties of the Moon is ongoing. These lunar soil samples collected in the young geological areas have unique physical and mechanical properties. This paper also introduces the basic situation of Chang' E 5 explorer and the process of sample collection. On the basis of summary of the existing research, the authors put forward some outlooks in the field of lunar geotechnical engineering in the future, including improving the biotechnology to achieve geotechnical fixation, lunar geotechnical testing and numerical simulation, and engineering construction on the lunar surface with low gravity, high radiation and vacuum environment.

RÉSUMÉ: Le succès des missions Chang'E-4 et Chang'E-5 a marqué la victoire progressive du projet chinois d'exploration lunaire.L'Université de Chongqing est responsable de la recherche et du développement de la charge utile de l'équipement biologique de la sonde Chang'E-4.Cet article présente la conception et l'essai de la charge utile de l'équipement biologique, ainsi que la germination et la croissance des organismes dans le bassin.Le succès de la germination des graines de coton a marqué la première fois que l'homme a cultivé des cultures extraterrestres.Chang'E - 5 a réussi à ramener sur terre des échantillons de roche et de sol prélevés sur la lune.L'étude des caractéristiques géologiques et géotechniques de la lune est en cours.Ces échantillons de sol lunaire prélevés dans de jeunes régions géologiques ont des propriétés physiques et mécaniques uniques.La situation de base et le processus d'échantillonnage de la sonde Chang'E - 5 sont introduits.Sur la base d'un résumé des résultats et des lacunes de la recherche existante, certaines perspectives d'avenir dans le domaine de l'Ingénierie géotechnique lunaire sont présentées, y compris l'amélioration de la technologie biologique pour réaliser la fixation géotechnique, l'essai géotechnique lunaire et la simulation numérique.La surface de la lune est construite dans un environnement de faible gravité, de rayonnement élevé et de vide.

KEYWORDS: Chang' E program; biological equipment payload; Chang' E explorer; lunar rock and soil; lunar environment.

1 INTRODUCTION.

The far side of the Moon has never been directly explored before the Chang'E-4 probe landed on the back of the Moon. On January 3, 2019, the Chang'E-4 probe arrived at the Von Kármá n crater, located in the South Pole-Aitken (SPA) basin, with the lunar rover Yutu-2 and the biological equipment payload (BEP) developed by Chongqing University. Chang'E-4 also became the first spacecraft soft-landing on the Moon's uncharted side never visible from the Earth (Jones 2019; Wang and Liu 2016).

The probe comprises of relay satellitia, a lander and a rover. The relay satellite called "Queqiao" is located at the mission orbit around the L2 translational point of the Earth & Moon. The relay satellite connects the Chang'E-4 lander and the rover on the back of the Moon with the command center on Earth. The lander is equipped with landing camera, laser three-dimensional imaging sensor, terrain camera, low-frequency radio spectrometer, lunar neutron and radiation dose detector and other equipment. The BEP is also fixed in the lander. The scientific detection instruments on the rover Yutu-2 include panoramic camera, lunar radar, infrared imaging spectrometer and neutral atom detector. These scientific equipment ensures the smooth landing and operation of Chang'E-4, and can carry out physical, geological, imaging and biological tests on the Moon (Liu et al. 2019; Tang et al. 2020; Zhang et al. 2020).

In order to give full play to the driving role of the lunar exploration project in the field of science and technology, and stimulate the enthusiasm and innovation potential of the public in exploring the universe, the creative design of lunar exploration payload was designed and organized to send biological equipment payload to the Moon. It is the first popular science payload to land on the back of the Moon, and it is also the first biological experiment on the Moon. The original idea of the experiment was to build a small recycling ecosystem in the lunar lander, which imitated the Earth's ecosystem. The first step is to make sure that the plant seeds germinate or eggs hatch in the lunar surface environment. The plan also includes showing the whole process of seed germination, seedling growth and blossom of plants under the lunar surface environment, or egg hatching, larva growth and development, and even flying to complete a life cycle in the future.

In general, the biological experiment on lunar surface a chieved the following four objectives:

1. To explore the growth as well as the photosynthesis effect of animals and plants on the lunar surface under conditions of low gravity, strong radiation and natural light;
2. Through the implementation of BEP, to promote the popularization of biological knowledge and deepen the understanding of biological principles;
3. Publicize the achievements of the lunar exploration project in China, stimulate people's interest in cosmic exploration and scientific research, and enhance people's awareness of environmental protection;

4. To achieve some hints or indications for future geotechnical engineering on the Moon

2 BIOLOGICAL EXPERIMENT

2.1 *Design of BEP*

In order to complete the development of BEP project, the team, after more than 50 times of design, optimization, analysis and other relevant work, finally determined the scheme, completed nearly 150 reports and more than 100 technical reports, and completed more than 100 engineering and biological verification tests. The team also completed 17 times of structural and thermal optimization, 12 times of complete mechanical simulation analysis, and 6 times of structural antecedent machining. The final configuration of test tank is shown in Figure 1.

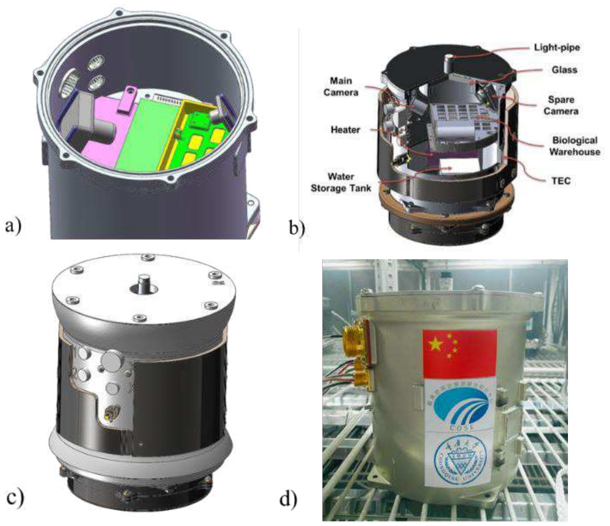

Figure 1. Structural design of BEP: (a) Plan view of the device in the tank (b) Schematic diagram of the position of the device in the tank (c) Overall appearance drawing (d) Physical picture.

In order to ensure the safety of on-orbit work, the tank structure parts are all processed by high-performance aluminum alloy, and the anti-corrosion treatment is carried out, which is verified by analysis and test. These tests include acceleration test, impact test, destructive pressure test, sinusoid and random vibration tests. In addition, the structural safety and mechanical properties of the tank in space environment are studied by numerical simulation. Some results of numerical simulation are shown in Figure 2.

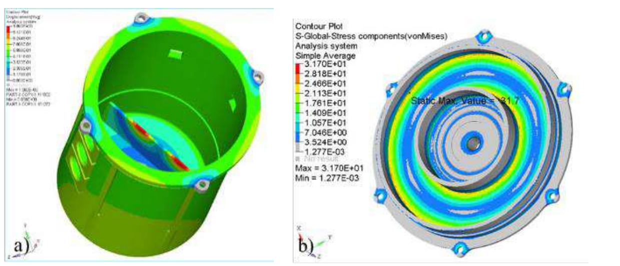

Figure 2. Numerical simulation of mechanical properties of tank: (a) The contour plot of maximum displacement of tank body (b) The contour plot of stress of the seal cover.

Aiming at the phenomenon of long-term weak air leakage at the low temperature of -57 ℃, it is solved by structural analysis, sealing material performance optimization and other methods. In order to maintain a stable temperature suitable for biological survival in the temperature range of - 60 to 80 ℃, through more than 20 times of thermal design and optimization, the combination of semiconductor cooler, electric heater, radiator and heat insulation measures is finally determined to realize the internal intelligent temperature control of BEP. Finally, the device passed thermal vacuum test, low temperature storage test and heat balance test.

In order to realize the photosynthesis of organisms in the tank (Xie et al. 2017), a light guide tube is left at the top of the device to guide sunlight into the tank, and a water storage tank is placed at the bottom (as shown in Figure 1). These additional openings require high air tightness of the device. Therefore, we did some sealing performance test, including helium mass spectrometry single point leak detection and completed integral leak detection by bell jar pressure change method. Some light guide performance test and fixation effect and dissolution test of water soluble cotton (shown in Figure 3) were also carried out in design processing.

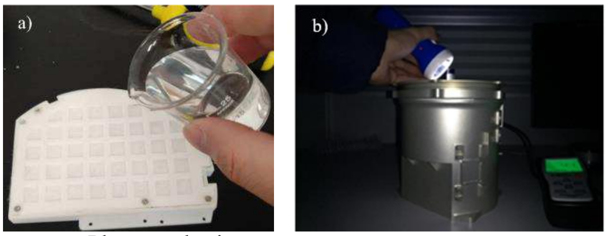
Figure 3. Photosynthesis performance test of BEP: (a) Fixation effect of water soluble cotton and its dissolution in water (b) Light guide performance test

2.2 *Position and structure of BEP*

BEP is located at the bottom of Chang'E-4 lander, as shown in Figure 4. The payload is composed of structure module, thermal control module, control module, light guide module, biological module and water tank. In order to meet the requirements of biological test, the load tank is equipped with air conditioning system, light pipe and water tank. The external insulation layer of the tank can withstand the test of severe temperature difference on the surface of the Moon; the internal air conditioning system with automatic temperature adjustment ensures that the environment is about 25 ℃ via the temperature sensor. In the tank, plants can absorb the natural light of the Moon through the light tube on the top cover plate of the load, and produce oxygen through photosynthesis. A water bag and electromagnetic pump with 18ML biological water were carried in the water tank. After landing on the Moon and power on, the lander received the ground instruction to render the electromagnetic pump work. The water in the water bag was released to the surface of the biological cabin through the water pipe to provide water for biological growth.

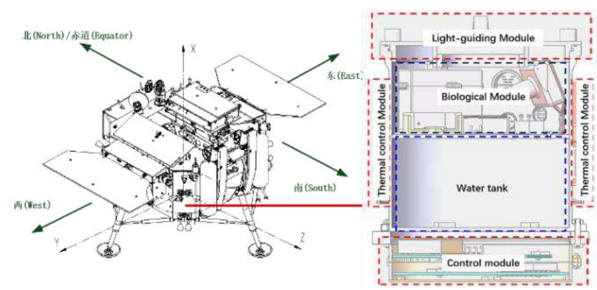

Figure 4. Position and components of BEP.

The BEP carries six kinds of organisms including potato, Arabidopsis, rape, cotton, Drosophila and yeast. The total weight of the load is 2.6kg. In addition, there are 18 ml of water, soil, air, thermal control and two cameras recording the growth status of organisms. The total weight is 2.608 kg, and the growth space of organisms is about 1 liter. The location of the modules and the distribution of various organisms are shown in Figure 5. The six organisms carried in the payload constitute a micro ecosystem with producers, consumers and decomposers. Among them, plants produce oxygen and food for all organisms to "consume"; as consumers, Drosophila and yeast decomposer produce carbon dioxide by consuming oxygen for photosynthesis. In addition, yeast can decompose plant and Drosophila waste to grow, and yeast can be used as food for Drosophila.

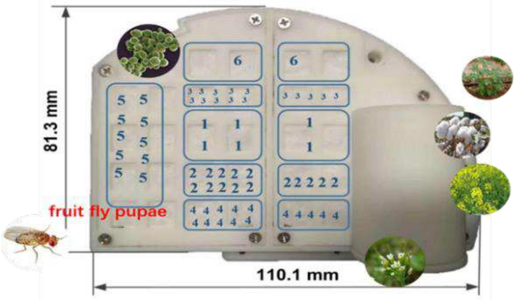

Figure 5. Layout of the modules and the distribution of various organisms

2.3 *Biological development process*

After the payload was powered on at 23:18 on the first day of Chang'E-4 landing on the Moon (January 3), the micro ecosystem in the payload began to enter the growth mode on the lunar. From the start-up to 20:00 on January 12, the ground sent the power-off command of the biological science popularization test load, and the load was shut down normally (Jones 2019). The photos sent back show that the seeds inside the payload germinated and the first green leaf grew on the barren lunar surface, which will provide research basis for human to establish a lunar base in the future. The photo of cotton seed germination is shown in Figure 6.

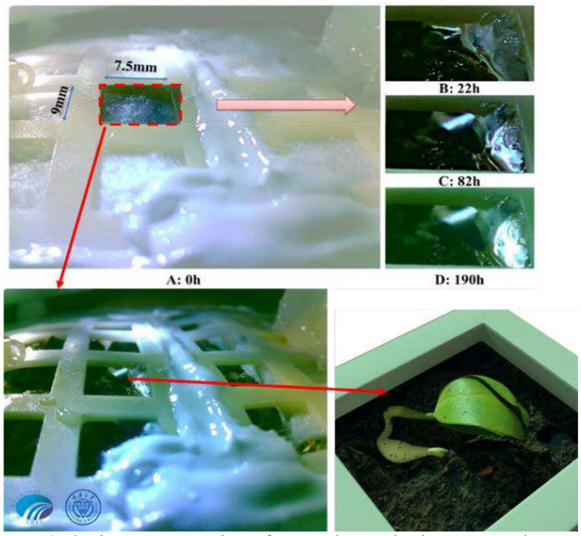

Figure 6 The image restoration of cotton leaves in the BEP on the Moon

To better understand how the plants, animals and microorganisms grow in the lunar environment with 1/6 gravity, low magnetic force, bright sunlight and radiation on the Moon, the other two identical BEPs were set up on Earth and start the experiments simultaneously with BEP on Moon at same temperature and intensity of illumination (as shown in Figure 7). The results showed that one of the cotton seeds successfully sprouted and turned green in the BEP on Moon. The germination of the cotton seed on Moon is much faster than that on Earth.

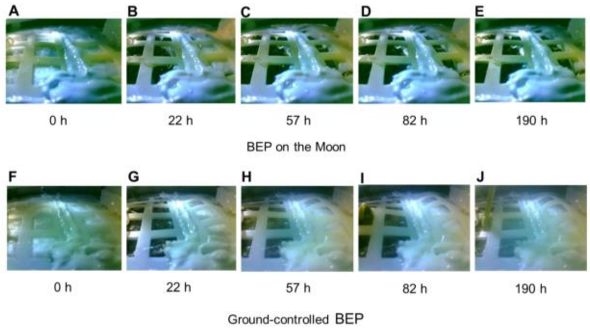

Figure 7. Camera captures of the ground-controlled BEP and the BEP on the Moon. A, B, C, D and E are the pictures captured 0 h, 22 h, 57 h, 82 h and 190 h after the WIT in the ground controlled BEP, respectively. F, G, H, I and J are the pictures captured 0 h, 22 h, 57 h, 82 h and 190 h after the WIT in the BEP on the Moon, respectively.

3 GEOTECHNICAL AND GEOLOGICAL OBSERVATIONS

3.1 *Path design of Yuetu-2*

Figure 8 shows the route of Yuetu-2. The lunar soil in the impact crater may become very loose and may make the wheels sink into it. In order to avoid these craters and get to the observation point designated by scientists, photos of the surrounding terrain at each step are taken, and then put together to form a complete topographic map. According to the photos sent back by the lunar rover and the survey results of the Chang'E-3 probe, the headquarters optimized the driving path to avoid the crater and guide the lunar rover to reach the target site with less energy consumption.

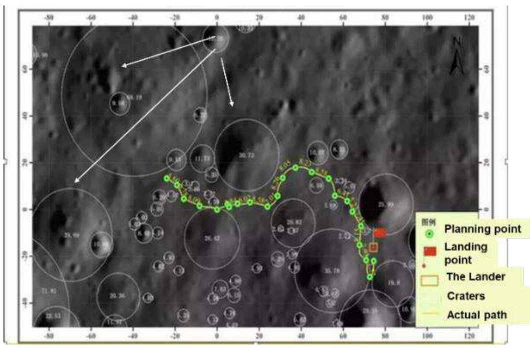

Figure 8. 3D image reconstruction and path optimization

3.2 *Geological information of the far side of the Moon*

For the Moon, there exist only two types of large-scale activity, meteorite impact and volcanic activity. Based on the scientific data obtained, the Chang'E-4 team revealed for the first time the geological stratification within 40 meters of the landing area on the back of the Moon, and expounded its role and evolution mechanism. Li et al. (2020) used the local positioning radar (LPR) to draw the schematic representation of the subsurface geological structure at the CE-4 landing site (as shown in Figure 9). The subsurface can be divided into three units: Unit 1 (up to 12 m) consists of lunar regolith, unit 2 (depth range, 12 to 24 m) consists of coarser materials with embedded rocks, and unit 3 (depth range, 24 to 40 m) contains alternating layers of coarse and fine materials.

As the longest working time probe on the Moon in history, Yuetu-2 lunar rover is still on the back of the Moon, exploring more lunar areas that have never been involved before. The researchers hope it will be able to observe the size changes of impact debris in the formation, thus revealing more details of the

Moon's ancient impact history. It can greatly improve our understanding of the history of lunar meteorite impact and volcanic activity, and may provide new ideas for understanding the geological evolution of the back of the Moon.

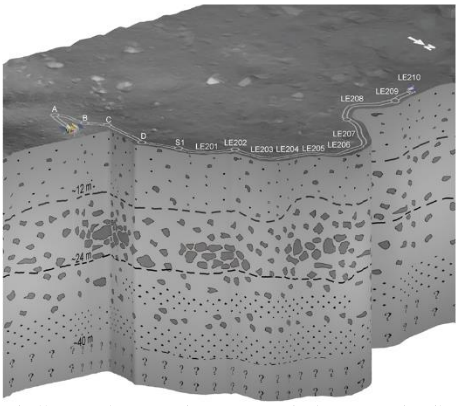

Figure 9. Shallow underground structure of Chang'E-4 landing area (Li et al. 2020).

4 CHANG'E-5 EXPLORER

The Chang'E-5 mission launched from Earth on 24 November 2020 and landed in the Storms Ocean of Moon on 1 December. This mission is China's first automated Moon surface sampling probe.

The Chang'E-5 is comprised of four components: an orbiter, a lander, an ascender, and an Earth return capsule (as shown in Figure 10). After touching down, the lander placed lunar samples into a vessel in the ascender. Then the ascender took off from the lunar surface to dock with the orbiter and the returner, which was circling the Moon, and transferred the samples to the returner. Having successfully transferred its Moon samples to the orbiter for return to Earth, the ascent vehicle later crashed itself into the lunar surface. The orbiter and returner then headed back to Earth, separating from each other when they were several thousand kilometers from Earth (Zhao et al. 2017). Finally, the returner reentered the Earth and landed in China at on 16 December.

Chinese scientists had hoped to collect up to 2 kg of pristine lunar surface samples of pebbles and regolith to a depth of up to 2 meters with a drill and scoops aboard the Chang'E-5 lunar lander. They took out the container loaded with lunar samples from the returner on 17 December. These samples collected could be the youngest samples retrieved from the Moon so far dating to roughly 1 billion years vs 3.1 to 4.4 billion years old for the Apollo samples(Qian et al. 2021; Qian et al. 2020).

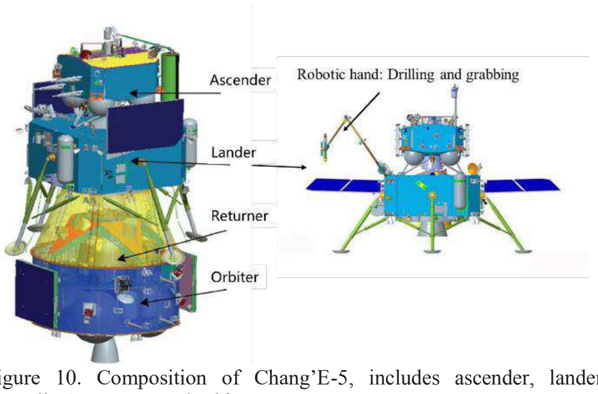

Figure 10. Composition of Chang'E-5, includes ascender, lander (sampling), returner and orbiter.

5 UNMANNED LUNAR SAMPLER

Chang'E-5 is equipped with two "sampling" modes: drilling a 2m deep soil sample with drilling tools and grabbing topsoil with robotic hand (as shown in Figure 10). The robotic hand could mine soil and rock samples from the Moon. The total length of the robotic hand is 3.7m, the structural weight is 3100g, and the arm thickness is only 1.4mm (Li et al. 2018). Test results show that the stiffness and dimensional stability of the robotic hand exceed the design requirements, which ensures the highly repeated positioning accuracy of the manipulator in the process of digging lunar soil and transferring samples (Liu et al. 2021). The collected lunar rock and soil were packaged like "sausage" to avoid contamination. Then the collected samples were sent to the ascender and returned to the Earth.

Lunar samples sent back to the Earth are mainly used for three purposes: scientific research, exhibition in the museum and international research cooperation. In the field of scientific research, the retrieved lunar rocks and soil can be used to investigate the origin of the Earth and the Moon, analyze the composition and the geotechnical properties of rock and soil, and prepare for the future development of lunar resources.

6 OUTLOOK OF GEOTECHNICAL ENGINEERING ON THE MOON

For geotechnical engineering construction and production activities, the low gravity, inactive geological activities, lack of water and pollution-free environment on the Moon are favorable for some underground construction. But on the other hand, the high radiation, the large temperature difference and the lack of atmospheric protection make the conventional geotechnical development difficult. Based on the advantages and disadvantages of these lunar environments, we put forward several possible geotechnical related construction activities on the Moon in the future.

1. Biological fixation technique in complicated mechanical environment: In the future, scientists and design engineers will improve the ecological system and organisms of landing on the Moon. Using the ecosystem carried in BEP and solar energy as inputs, the materials (such as water, silicon and nitrogen) on the Moon are fixed in the extreme environment to form a positive cycle ecosystem. On the basis of microbial immobilization of inorganic substances (Chen et al. 2021), we expect to cultivate green plants on the Moon, including grass and shrubs (Bordoloi and Ng 2020; Ng et al. 2021;Fu and Zhang 2019). The roots of these plants can fix the soil on the surface of the Moon and be decomposed by microorganisms to produce organic matter, which can improve the soil environment of the Moon and provide a reliable geotechnical environment for large-scale human migration to the Moon. In addition, the research on interaction between geotechnical systems and the environment as well as the bio-inspired geotechnics is essential (Zhong et al. 2021).
2. Light guide technique of lunar surface under natural conditions: The basis of life activities on the Moon is the energy provided by sunlight. Since the optical guide tube itself does not have the sealing performance, new techniques would be developed to introduce sunlight into living areas or improve the airtightness of light guide tubes to reduce the internal gas leakage and ensure sufficient lighting.
3. Autonomous temperature control under small scale, high humidity and significant temperature difference: The BEP thermal control module consists of heat insulation pad, heat sink, multilayer, heat insulation ring and control module shell. These temperature control devices have achieved

miniaturization, but there are still large deficiencies in heating efficiency. In the future, it is hoped that the use of the helium-3 material in the lunar rock and soil as the raw material for nuclear reaction to provide enough heat for residential areas, which is important for biological and growth geotechnical improvement (Xiao et al. 2021).

4. Soil mechanical and permeability properties under low gravity and strong radiation environment: In order to study the rock and soil under Moon's environment, it is essential to reproduce the dry, low gravity and high radiation environment similar to the Moon in the Earth's laboratory. In fact, it is very difficult to produce this kind of special environment. The existing technical means can make the environment with low gravity and high radiation, but the cost is too high, and it is difficult for the test personnel and equipment to work for long time. Therefore, numerical simulation may be a better solution (Gustafson et al. 2008; Xi et al. 2020).
5. Lunar rock and soil reproduction and simulation: The study of physical and mechanical properties of rock and soil is the basis of engineering construction. Scientists all over the world will conduct laboratory analysis and testing by collecting lunar rock and soil samples sent to Earth, and generate numerical models according to the obtained physical parameters (such as mechanical properties, composition, water physical properties, etc.), and use numerical simulation to carry out large-scale research work (Wang et al. 2020; Zhou et al. 2020).
6. Thermal-hydraulic-microgravity-chemical-radiation multi field and multi scale geotechnical problems: The distribution and coupling changes of stress field, chemical field, thermal field and migration field in the reconstructed lunar rock or lunar soil will be studied according to the low gravity and high radiation environment like it on the Moon. In fact, due to the complexity of the lunar environment, many of the multi field coupling laws verified on Earth will be different in the lunar environment (as shown in Figure 11). This requires scientists to carefully verify and propose a suitable multi field coupling calculation method on the premise of giving full play to their imagination.
7. Building with 3D printing of lunar materials: According to the studied properties of lunar rock and soil, combined with the geological data of the landing site on the Moon, we can develop survival base on the Moon with 3D printing and other reinforcement technology (Lane et al. 2016). 3D printing technology is a kind of construction technology especially suitable for the Moon environment. It can realize unmanned manufacturing, use the materials on the Moon to build structures, and improve the materials and structures to create shelters that can absorb radiation(Ma et al. 2019; Ma et al. 2018). With the study of lunar geotechnical materials and the development of 3D printing technique, 3D printing products on the Moon are quite possible.
8. Exploitation and utilization of lunar geological resources under microgravity conditions: Due to the lack of geological activities and low gravity on the Moon, it may be easier to achieve geotechnical stability on the Moon than on Earth. But at the same time, the high radiation environment and meteorite impact are the problems that must be considered in the open excavation and underground roadway protection on the Moon.

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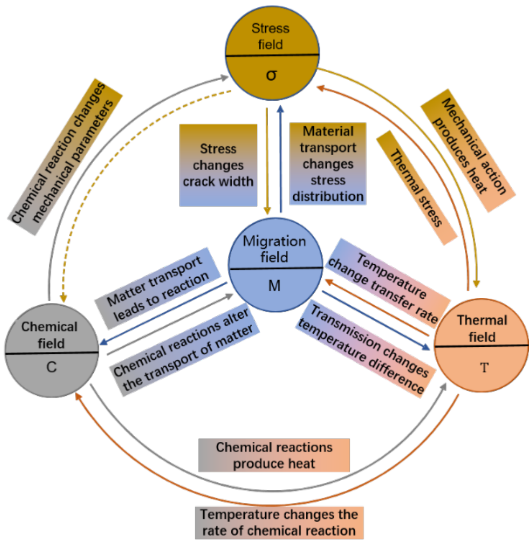

Figure 11. The multi field coupling laws commonly used in the field of geotechnical engineering may be different in the lunar environment.

8 REFERENCES

Bordoloi S, Ng CWW. 2020. The effects of vegetation traits and their stability functions in bio-engineered slopes: A perspective review. *Engineering Geology* 275

Chen Y, Gao Y, Ng CWW, Guo H. 2021. Bio-improved hydraulic properties of sand treated by soybean urease induced carbonate precipitation and its application Part 1: Water retention ability. *Transportation Geotechnics* 27

Fu Y, Zhang W. 2019. Effects of soil moisture content and root depth on anti-overturning performance of Ginkgo biloba seedings. Journal of Civil and Environmental Engineering 41 (5): 42-48.

Gustafson RJ, White BC, Gustafson MA Development of a High Fidelity Lunar Soil Simulant. In: Space Technology & Applications International Forum-staif, 2008.

Jones A. 2019. China grew two leaves on the moon: The Chang'e-4 spacecraft also carried potato seeds and fruit-fly eggs to the lunar far side - [News]. *IEEE Spectrum* 56,9-10

Lane B, Moylan S, Whitenton E, Ma L. 2016. Thermographic Measurements of the Commercial Laser Powder Bed Fusion Process at NIST. *Rapid Prototyp J* 22,778-787

Li C et al. 2020. The Moon's farside shallow subsurface structure unveiled by Chang'E-4 Lunar Penetrating Radar. *Sci Adv* 6,eaay6898

Li Y, Lu W, Fang G, Shen S. 2018. The Imaging Method and Verification Experiment of Chang'E-5 Lunar Regolith Penetrating Array Radar. *IEEE Geoscience and Remote Sensing Letters* 15,1006-1010

Liu J et al. 2019. Descent trajectory reconstruction and landing site positioning of Chang'E-4 on the lunar farside. *Nat Commun* 10,4229

Liu T, Zhou J, Liang L, Zhao Y, Cao D. 2021. A novel torque analysis method for drilling deep lunar soil by DEM. *Journal of Terramechanics* 94,23-37

Ma G, Li Z, Wang L, Wang F, Sanjayan J. 2019. Mechanical anisotropy of aligned fiber reinforced composite for extrusion-based 3D printing. *Construction and Building Materials* 202,770-783

Ma G, Zhang J, Wang L, Li Z, Sun J. 2018. Mechanical characterization of 3D printed anisotropic cementitious material by the electromechanical transducer. *Smart Materials and Structures* 27

Ng CWW, Zhang Q, Ni J, Li Z. 2021. A new three-dimensional theoretical model for analysing the stability of vegetated slopes with different root architectures and planting patterns. *Computers and Geotechnics* 130

Qian Y, Xiao L, Head JW, van der Bogert CH, Hiesinger H, Wilson L. 2021. Young lunar mare basalts in the Chang'e-5 sample return region, northern Oceanus Procellarum. *Earth and Planetary Science Letters* 555

Qian Y et al. 2020. The regolith properties of the Chang'e-5 landing region and the ground drilling experiments using lunar regolith simulants. *Icarus* 337

Tang Z et al. 2020. Physical and Mechanical Characteristics of Lunar Soil at the Chang'E-4 Landing Site. *Geophysical Research Letters* 47

Wang Q, Liu J. 2016. A Chang'e-4 mission concept and vision of future Chinese lunar exploration activities. *Acta Astronautica* 127,678-683

Wang Y, Wang L, Meng F, Chen K. 2020. Strength test of 3D printed artificial rock mass with pre-existing fracture. *Underground Space*

Xi B, Jiang M, Cui L. 2020. 3D DEM analysis of soil excavation test on lunar regolith simulant. *Granular Matter* 23

Xiao Y et al. 2021. Homogeneity and mechanical behaviors of sands improved by a temperature-controlled one-phase MICP method. *Acta Geotechnica*,1-11

Xie B et al. 2017. The water treatment and recycling in 105-day bioregenerative life support experiment in the Lunar Palace 1. *Acta Astronautica* 140,420-426

Zhang L, Li J, Zeng Z, Xu Y, Liu C, Chen S. 2020. Stratigraphy of the Von Kármán Crater Based on Chang'E-4 Lunar Penetrating Radar Data. *Geophysical Research Letters* 47

Zhao J, Xiao L, Qiao L, Glotch TD, Huang Q. 2017. The Mons Rümker volcanic complex of the Moon: A candidate landing site for the Chang'E-5 mission. *Journal of Geophysical Research: Planets* 122,1419-1442

Zhong W, Liu H, Wang Q, Zhang W, Li Y, Ding, Chen Longlong. 2021. Investigation of the penetration characteristics of snake skin-inspired pile using DEM. Acta Geotechnica. DOI: 10.1007/s11440-020-01132-2

Zhou S, Lu C, Zhu X, Li F. 2020. Preparation and characterization of high-strength geopolymer based on BH-1 lunar soil simulant with low alkali content. *Engineering*