Technical aspects of space constructions and bases

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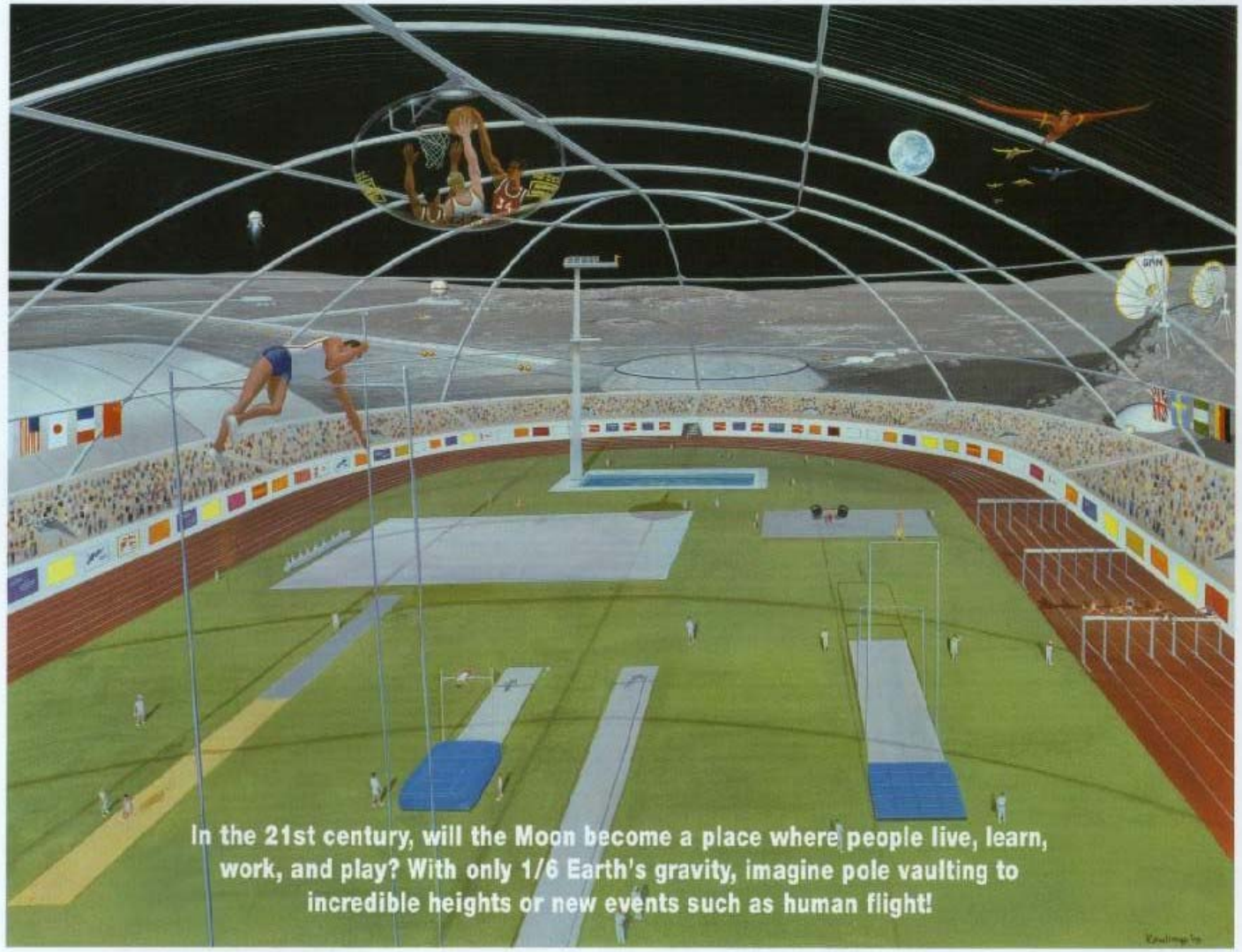
Thomas Tredgold, 1828

"That species of knowledge which constitutes the profession of Civil Engineering; being the art of directing great sources of power in Nature for the use and convenience of man, as the means of production and of traffic in States both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial power for the purpose of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns."

National Aeronautics and
Space Administration

The Lunar Games



In the 21st century, will the Moon become a place where people live, learn, work, and play? With only 1/6 Earth's gravity, imagine pole vaulting to incredible heights or new events such as human flight!

A NEW NATURE (1)

- Lunar gravitation is 1/6 of that on Earth
- There is no atmosphere on the Moon
- There is no global magnetic field on the Moon.
- The same side is always facing the Earth
- 1 lunar day is equivalent to 27.3 terrestrial days, half with sunlight, half with darkness on lunar equator.

A NEW NATURE (2)

- The lunar surface temperature is predicted to show a fluctuation such that the range is (between -170^0C and $+120^0$C on the equator) 3 times greater than that on the Earth, with a minimum of approximately -250^0C at the poles. It has also been measured that temperatures 30cm below ground surfaces remained relatively constant at $-56\ ^0$C with a slight variation of only 2^0 to 4^0C. [Lin et al, 1991]
- The surface of the moon is continuously exposed to a flux of cosmic radiation. This effect considerably increases during daytime, due to solar radiation.

A NEW NATURE (3) (ATMOSPHERE)

The thin atmosphere of the Moon allows even the smallest micrometeorites to impact with their full cosmic velocities. This bombardment poses a hazard to all surfaces exposed on the lunar surface, especially to delicate materials like telescope mirrors and coatings.

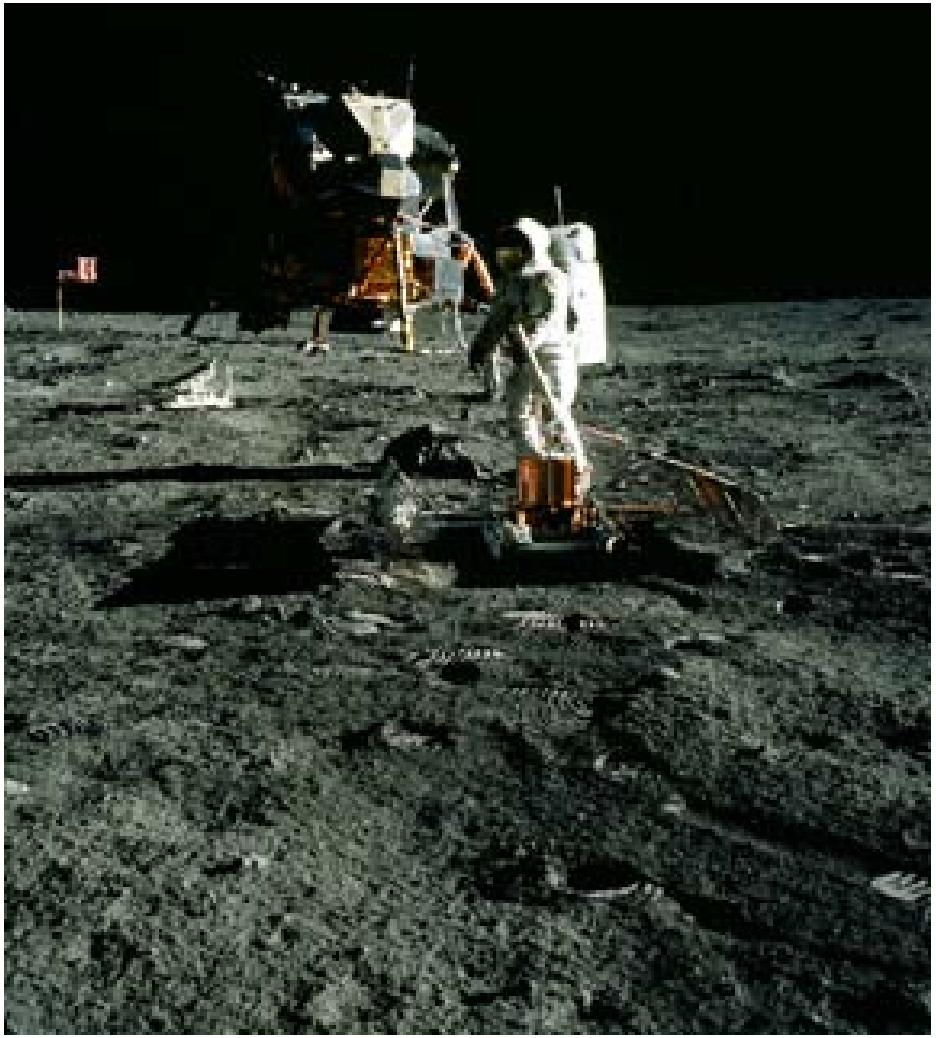
A NEW NATURE (4) (EXISTENCE OF WATER)

- Research has indicated water ice presence at both the north and south lunar poles. Data from Lunar Prospector was indicating the possible presence of discrete, confined, near-pure water ice deposits buried beneath as much as 400 mm of dry regolith, with the water signature being stronger at the north pole than at the south. The estimated total volume of ice was 6.6 billion tons. Uncertainities in the models was obliging the scientists to state that this estimate could be off considerably. Effectively, and on purpose impact (July 31, 1999) of Lunar Prospector “produced no observable signature of water”. A very similar experiment performed last year has proved the existence of water on the Moon.

A NEW NATURE (5) (SEISMICITY)

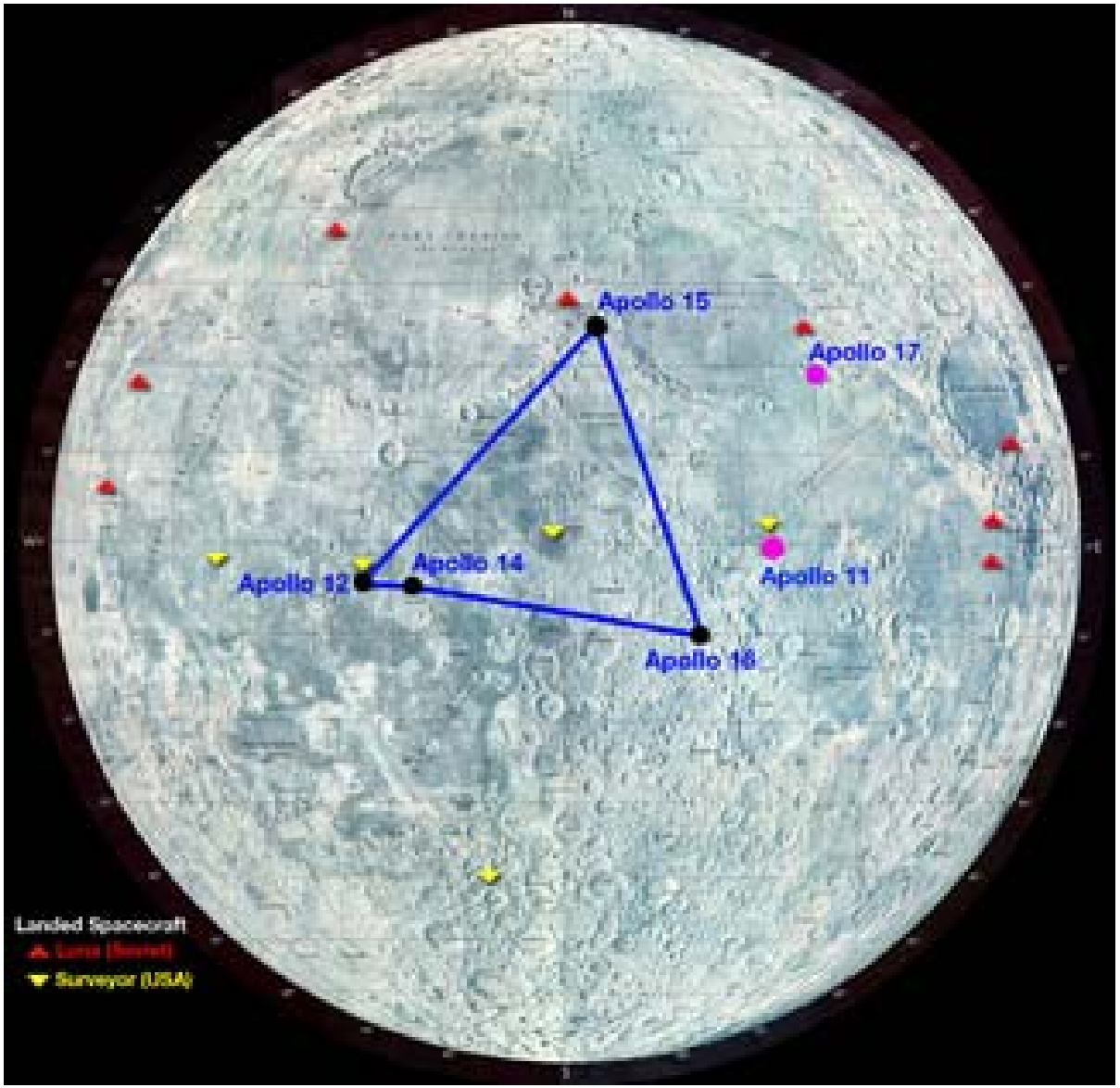
The analysis of Apollo seismic database revealed the existence of four different types of lunar seismic events.

- Thermal moonquakes (small magnitude),
- Deep moonquakes (abundent in number, less than Richter 2, related with tidal effects),
- Meteoroid impacts (1700 larger than 0.1 kg in number in 8 years), and
- Shallow moonquakes (50-200 km deep; 28 events, 7 of which were greater than 5, probably due to dissimilar geological features).



Astronaut Buzz Aldrin sets up a seismometer on the moon in 1969. A network of seismometers operated on the moon and recorded "moonquakes" there until the experiment was shut down in 1977. Renewed interest in moon exploration is spurring new lunar seismic efforts. Neil Armstrong took this picture

The Apollo Passive Seismic Experiment involved deployment of a network of seismometers (outlined in the large triangle) on the nearside of the moon. The seismometer at Apollo 11's landing site failed after 21 days. The Apollo 17 seismometer was intended to determine the shallow structure of the site and was switched off once the experiment was complete



Earth-Moon Differences

- Terrestrial Nature

- Lunar Nature
- Difficulties of transport of manpower and resources
- Difficulty of maintenance
- Low efficiency of workmanship
- High degree of risk

Geotechnical Engineering

Regolith, the soil formed by the continual bombardment of the lunar rocks by micrometeorites.

Properties as to grain size, bulk density, porosity, surface area, shear strength, adhesion, …

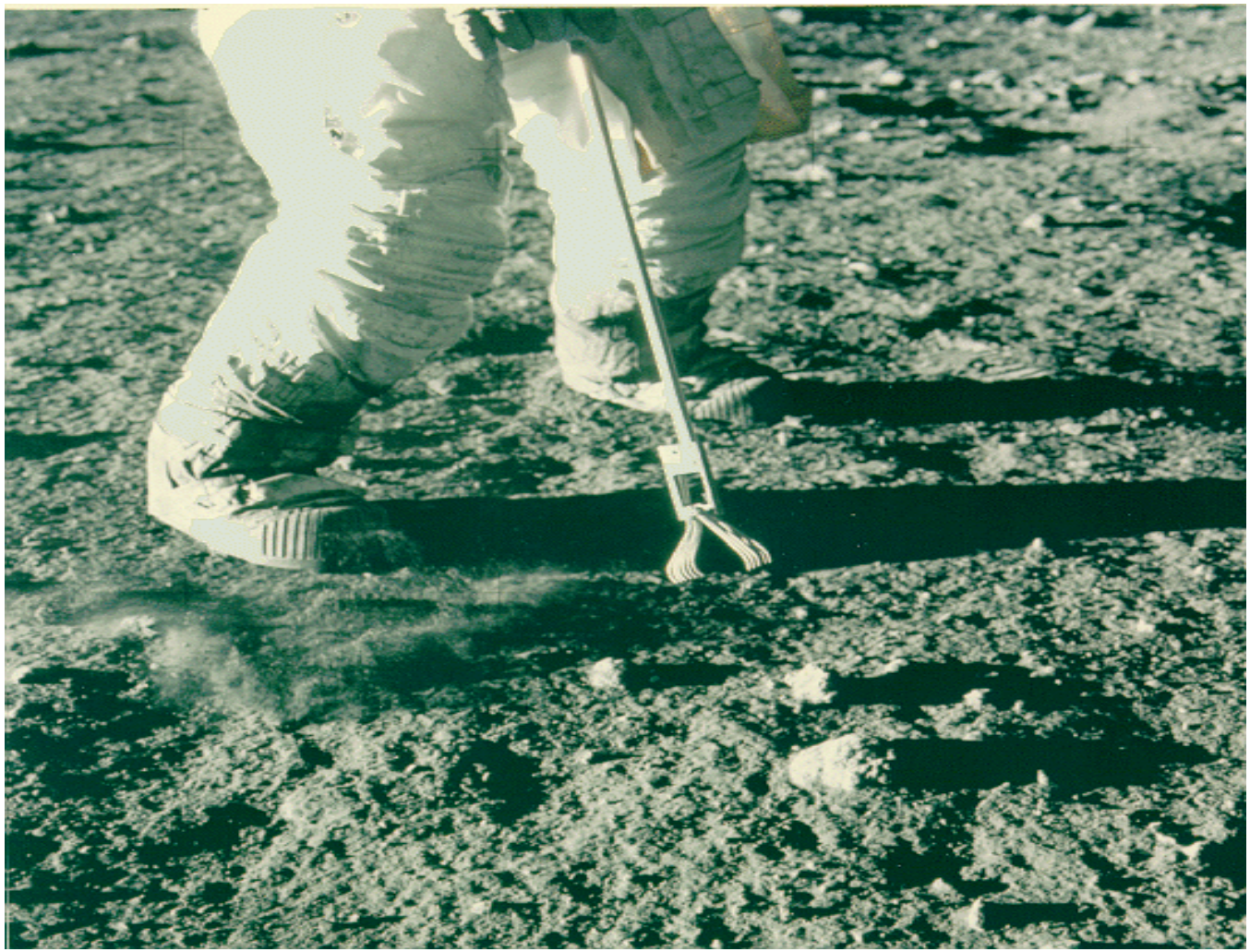
Modulus of subgrade reaction: Typically 1000 $kN/m^2/m$ which means 10 mm settlement under a pressure of 10 kN/m^2

Thickness: Average 4-5m (ranging between a few cm's to some tens of meters)

Apollo 15 Soil Mechanics Investigation

The Self-Recording Penetrometer being used in training

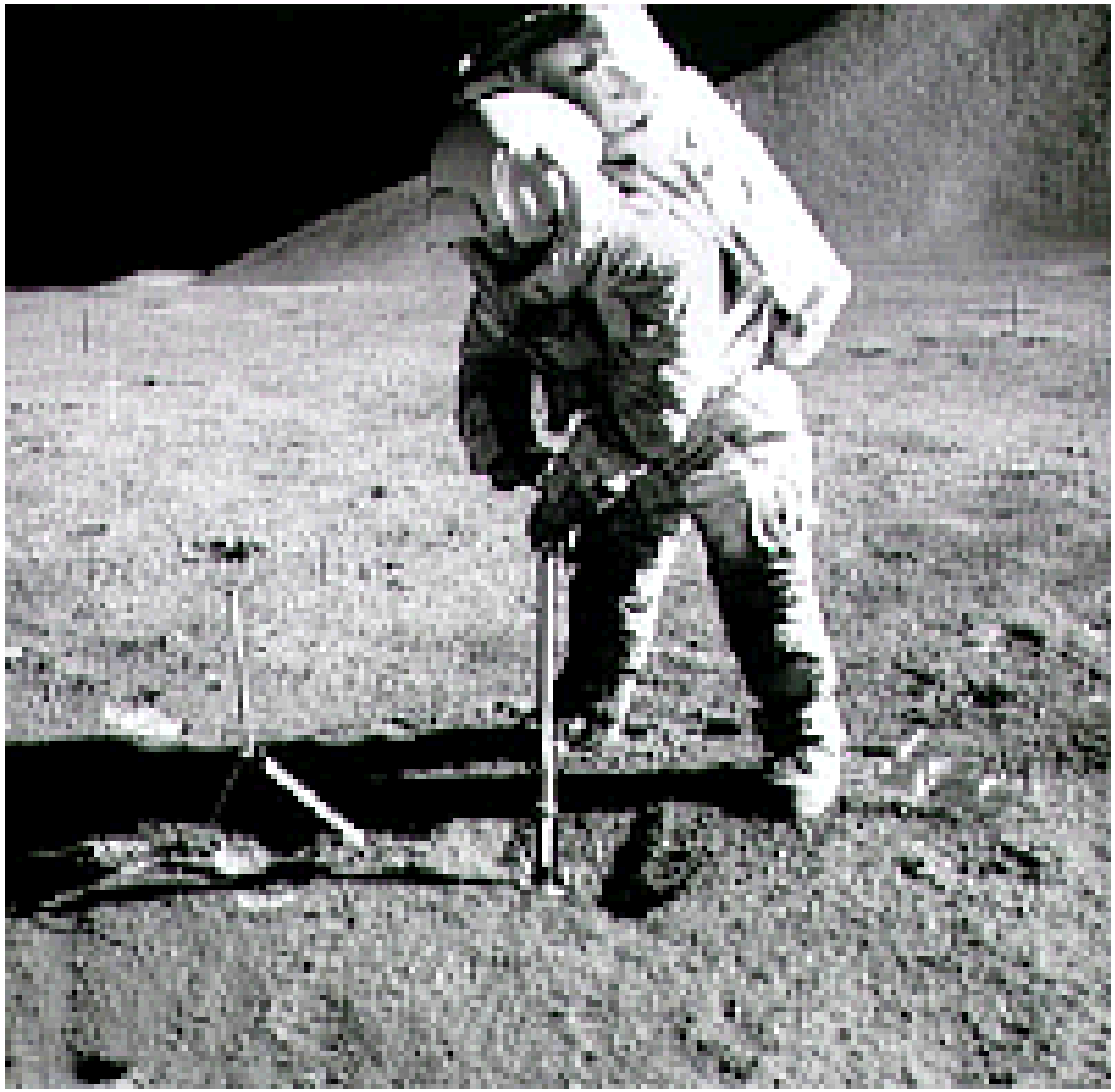
Picking up Rock Samples. *Apollo 12*



Collecting Soil Samples *Apollo 17*

Apollo 17 Astronaut Jack Schmitt Using a Rake

Collection bag attached to astronaut's backpack. *Apollo 17*



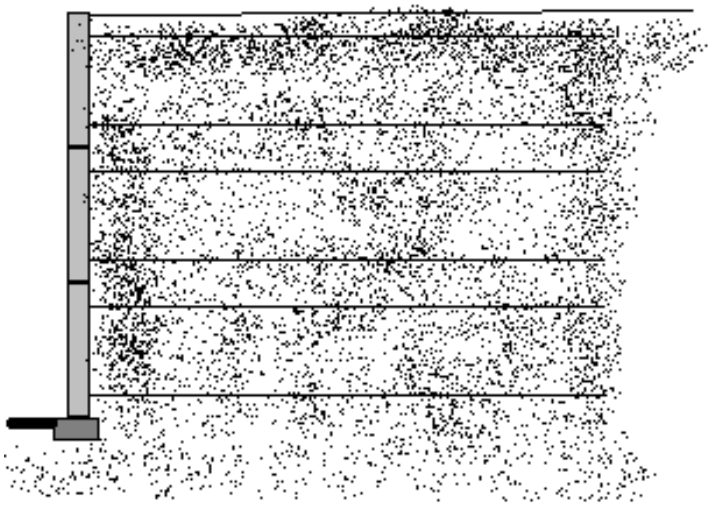
Regolith provides a good protection medium against radiation and micrometeorites.

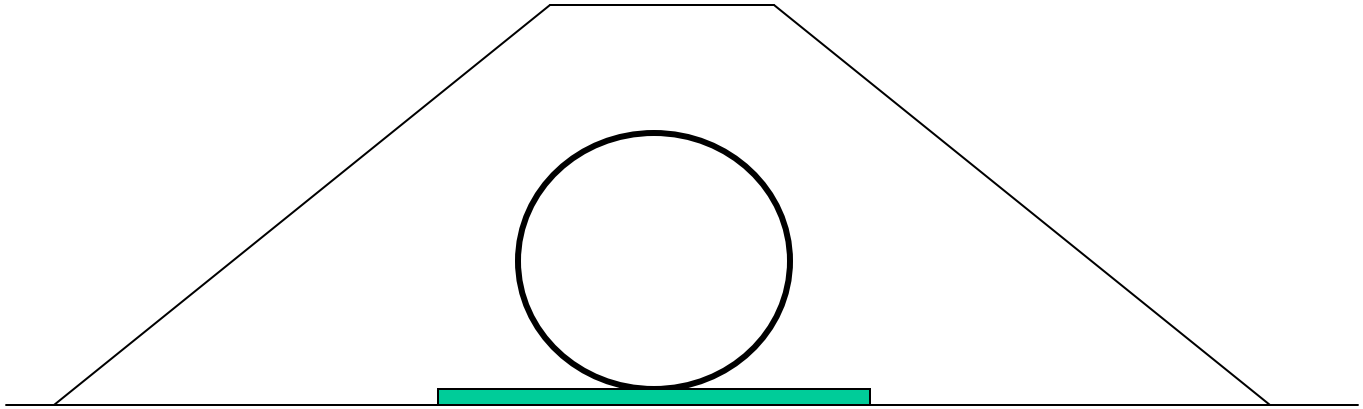
Estimate: ~2 m.> sufficient protection

Pressed, prefabricated blocks of regolith for smaller thicknesses.

It can be used as a raw material also for many other applications, the most important being concrete production.

Reinforced Regolith - ReRe





STRUCTURAL ENGINEERING

- Choice of Structure

  Type of Structure

  Resistant to radiation, micrometeorites and moonquakes.

  Shielding (using regolith) or underground (lavatubes e.g.

  Easy to construct/mount

  At the beginning using terrestrial resources, but as the time goes on, using lunar resources

- Design of Structures

  Loads

  Gravity Loads 1/6

  Inside pressure 1 ~ .85atm

  85~100 kPa

  Structures will resist compressive forces and/or tensile forces, thus the name tension-compression-column

  Optimisation to highest degree.

$30m^2$ surface area

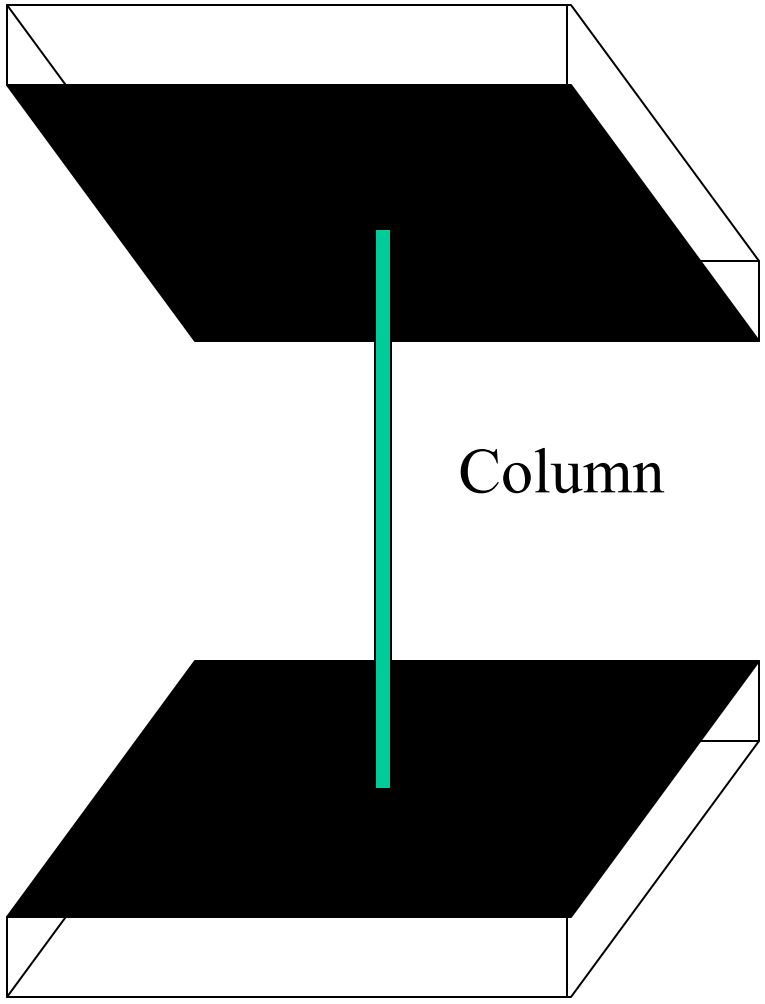
U.D.L. 5 kN/m^2

Total downward load: 150 kN

σ_{all}=200MPa

A_{min}=750mm^2

27mmx27mm



$30m^2$ surface area
Total structural downward load:
150/6=25 kN

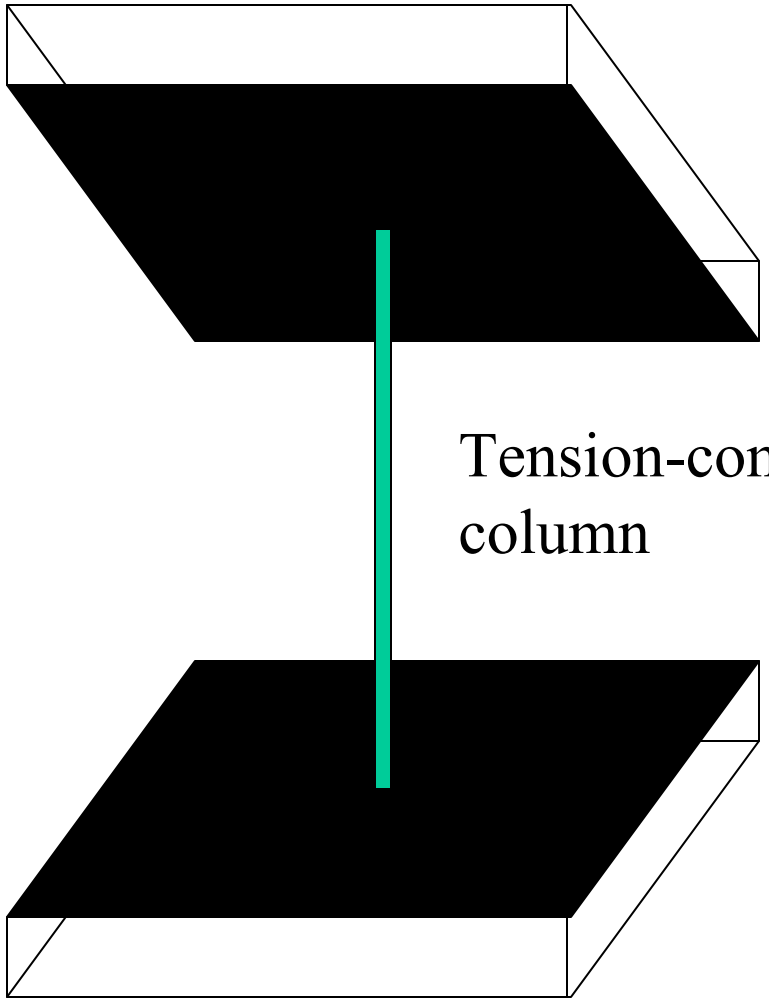
2m thick regolith
1500 kg/m^3 x 10/6N/kg x 2 m = 5000 N/m^2,
>>>>150 kN
Total compressive load
175 kN.

Inside pressure
1atm=$1x10^5$Pa
Total tensile force 3000 kN

-175kN < F < 2825kN
σ_{all}=200MPa

A_{min}=~14000mm^2

118mm x 118 mm



Tension-compression column

Comparison for 30m2 area

	Earth	**Moon**
Downward structural load	150 kN	25 kN
Regolith cover	0	150 kN
Total Comp. Ld.	150 kN	175 kN
Tensile Force	0	3000 kN
Force Limits	-150 / 0 kN	-175 / 2825 kN
Steel area	750mm2	14000mm2

Choice of structures

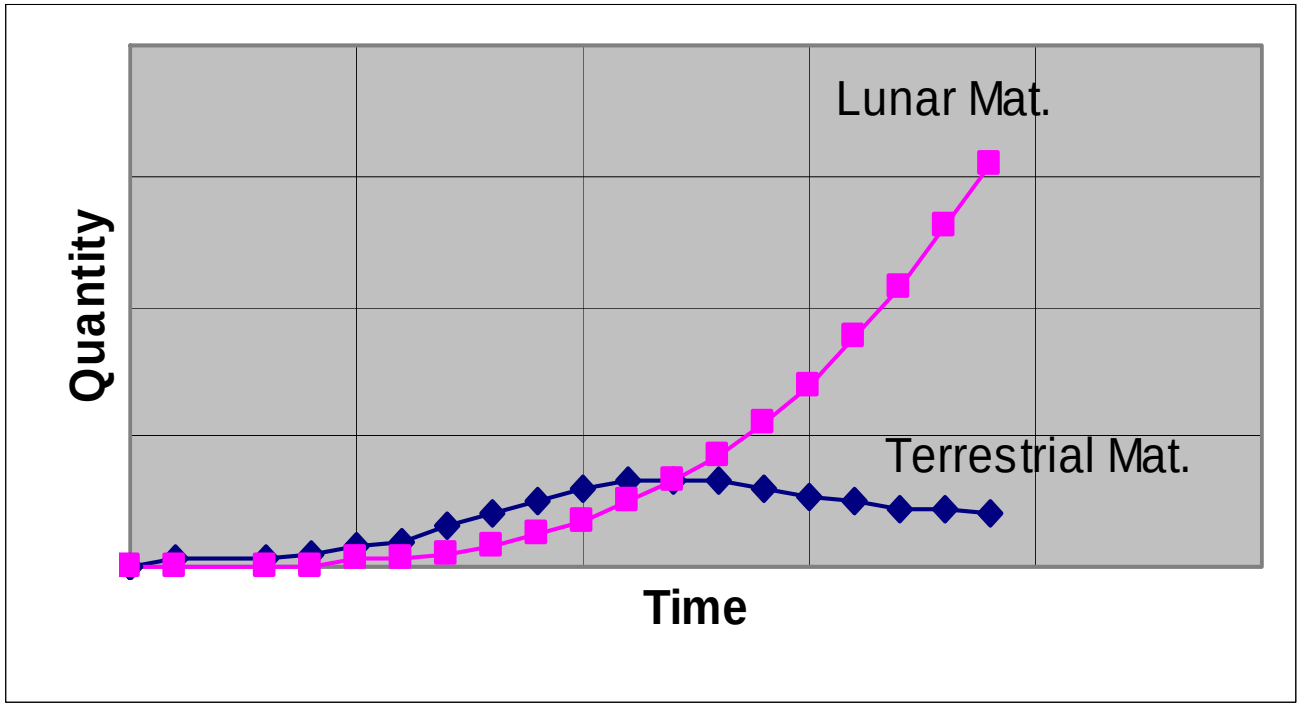
- Tension resistant

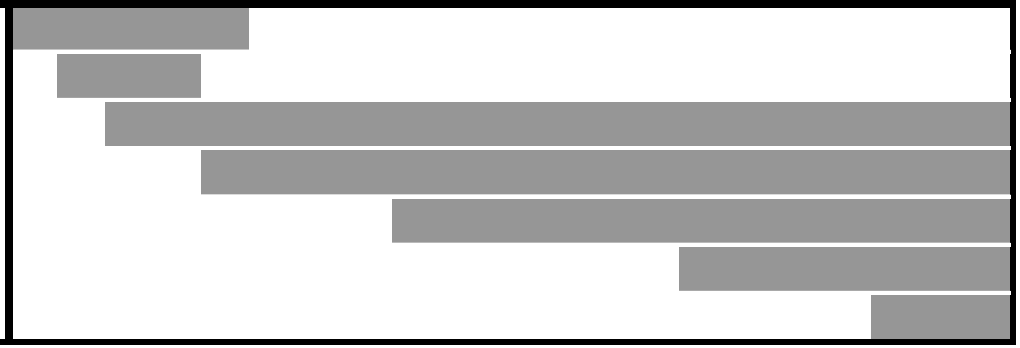
  Spherical or like (ellipsoidal, toroidal, cylinderical),
- Spherical structures connected to each other by cylinderical tubes
- Inflatable structures
- Tensegrity (tensile-integrity) structures
- Prestressed or post-tensioned lunar concrete
- Important shielding (or underground)

MATERIALS OF CONSTRUCTION

- A completely new era
- Three basic research areas:

- Lightweight tensile resistant materials
- Exploitation of local materials
- Behavior under lunar conditions


Lunar Mat.
Terrestrial Mat.
Quantity
Time

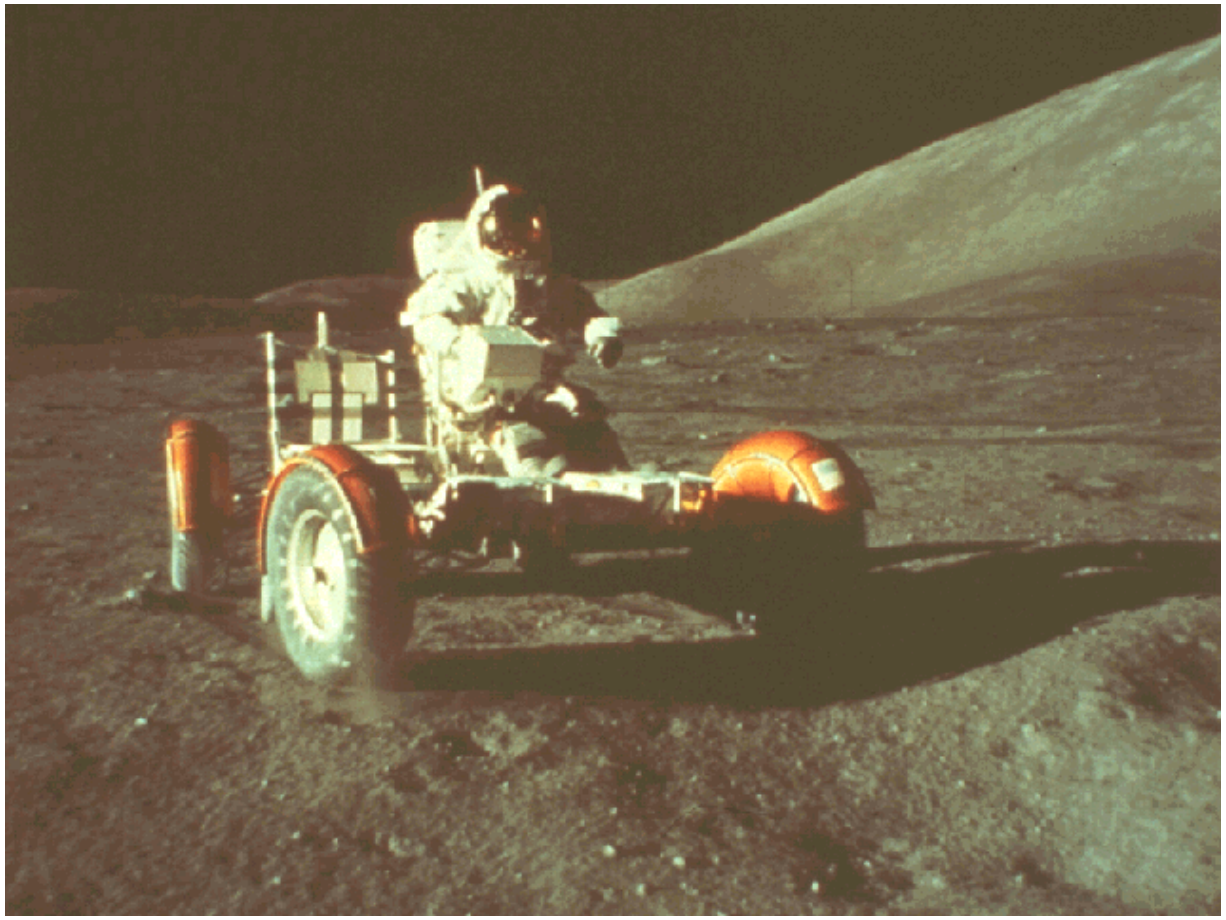
Habitat type and construction materials	Time
Landing vehicles	
Deployed prefabricated structures	
Regolith used as shielding	
Regolith derived concrete for compression	
Lunar structural metal reinforcement	
ISRU production of airtight sealing	
Fully self-sufficient ISRU construction	

TRANSPORTATION ENGINEERING

- Lunar vehicles
- Lunar Railroads
- Cable Transportation

- One important problem is lubrication in this dusty medium.

APOLLO 17



Lunar Dust and Duct Tape

Credit: Apollo 17, NASA

CONSTRUCTION MANAGEMENT

- SITE PLANNING AND SITE CHOICE
- SCHEDULING OF OPERATIONS
- CONSTRUCTION EQUIPMENT
- COST ANALYSIS, COST CONTROL

SITE PLANNING AND SITE CHOICE

Location of site

The polar sides are believed to have the advantage of containing water ice. Especially southern pole [i)ice, ii)largest impact crater, iii)permanently shadowed crater bottoms, iv)places with almost continuous sunlight, v)constant temperature ~-30C, vi)close to farside]

Planning of site

In addition to similar problems on Earth, landing areas and their preparations have to be considered

SCHEDULING OF OPERATIONS

Risk factor. Follow up very closely.

CONSTRUCTION EQUIPMENT

Soil resistance is similar.

Weight of equipment is low. Thus an anchoring system or downward push is necessary.

COST ANALYSIS, COST CONTROL

A new data base will be formed.

New Issues in Lunar Constructions

- Robot technology, intelligent, tele robots
- New equipment with less weight
- Advanced materials, tensile resistant, lightweight
- Adoption to new environments, re-re
- Advanced optimization techniques
- Advanced computational methods
- Interdisciplinary and multidisciplinary engineering
- Local resources
- Education

Feedback

- Research carried on lunar bases will have a great impact on the applications on the Earth.
- New materials
- Automated construction and monitoring
- Use of robots
- Habitations in any environment
- Advanced computational methods (nonlinearity, intelligent/active structures)

Feedforward

- Open the way to and easen the design and construction of bases and settlements on other space objects

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