CONSTRUCTION OF LARGE UNDERGROUND SETTLEMENTS ON THE MOON OR ON MARS

1. Introduction

Constructing underground structures is generally very expensive and requires significant mechanisation, manpower and materials. So, traditional underground construction techniques would not be viable for use on the Moon or on Mars. This paper presents some ideas for underground construction on other planets, based on the concept used for creating underground structures on Earth. This earth-focused concept is described in a paper that can be viewed at: https://deeepunderground.com/underground.html

2. Mechanisation for Underground Construction

Based on this concept, there are two kinds of mechanisation that should be used for underground construction:

- Drilling mechanisation
- Mechanisation for widening drill holes

Drilling mechanisation was developed for several missions to the Moon and Mars that have taken place over the past 40 years, mostly for taking soil and rock samples. The weight of the machines used was typically below 10kg and the machines were able to take samples from 0-1m below the surface in question. For deeper boreholes, different technology was developed that could potentially drill hundreds or even thousands of metres below the surface.

JSC and private firms have been developing an autonomous Mars drill since 2001. Prototypes were tested in challenging conditions. The drill machine uses an electrically-powered down-hole expanding unit, which is lowered on the end of a cable, locked to the sides of the hole and pushed down from there. The goal was to develop the device to be low in mass (~20kg) and relatively low in electrical power consumption (~60W).

For our concept, a stronger drilling machine is needed. We would need to be able to drill a borehole of 10cm diameter and 100m in length, which would probably require:

- Up to 100kg of weight (earth)
- Electrical power ~500W
- Drilling progress 2m of depth/day

Mechanisation for widening boreholes is yet to be developed. It should consist of:

- Steel beam (pipe) of 100m length and a diameter of 5cm
- A tent (there must be air in the borehole)
- A fan at the bottom of the borehole for removing dust
- A borehole edge-cutting device able to cut the edges of the borehole at multiple levels

At present, such a machine has not been developed. But, let's suppose it will have the following properties:

- Up to 200 kg of weight (earth)
- Widening progress 1cm of 100m-long borehole/day

To summarise, one drilling machine is able to drill 100m in 50 days, and one widening machine is able to widen one borehole of length of 100m to a diameter of 300 cm in 150 days.

3. Geological Conditions on Mars and the Moon

We don't know much about geology on Mars or the Moon, at least not what the conditions are like deep underground. However, there are some signs that underground construction would be possible. For example, there are signs of caves and large pits on Mars and the Moon, which suggests that the ground material is strong enough to allow construction of underground facilities without the need for support measures.

4. Underground Construction

The most effective way to build stable underground constructions is to excavate several tunnels side by side and then cut the walls between them at certain places, in order to connect the tunnels. This kind of construction requires minimum excavation, but allows the construction of a large room, separated by pillars, as shown in Figure 1. Figure 2 shows an Earth version of an underground facility built using this concept.

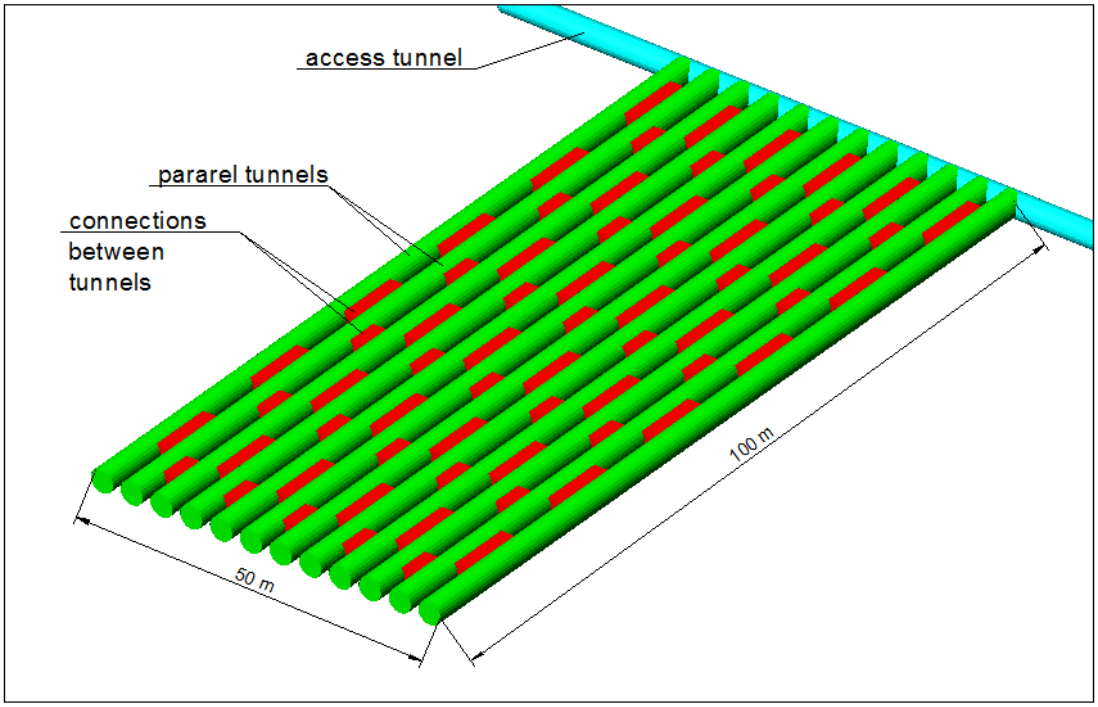

Figure 1. Shape of excavated underground facility

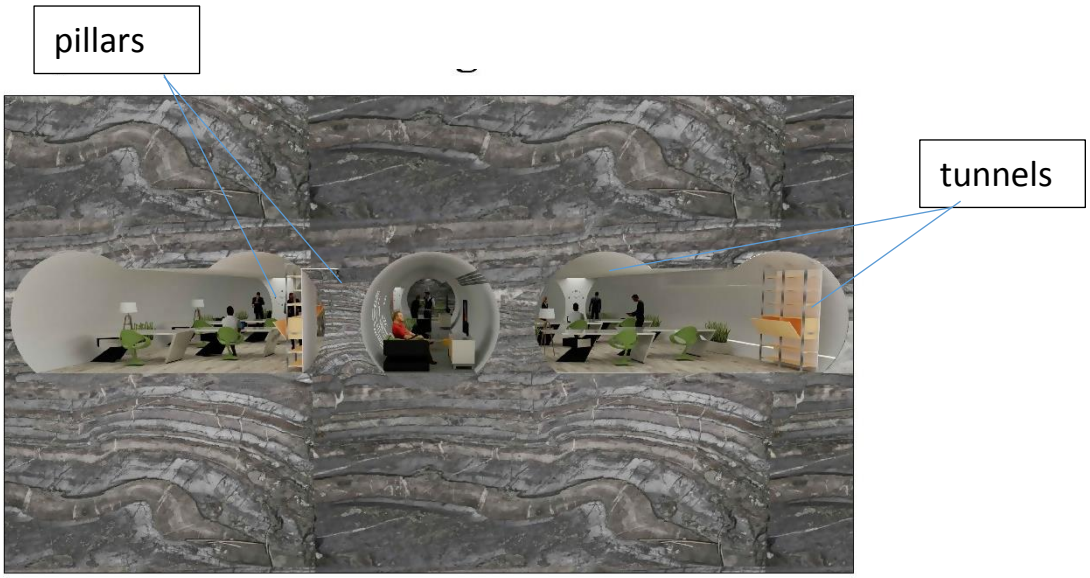

Figure 2. Earth version of underground offices (artist's impression)

Since the tunnels are circular, and separated by central pillars, they should be stable even without additional support measures, even if the middle pillars are removed in certain places. This would allow free movement around the facility, similar to a flat with multiple rooms that are separated by walls.

5. Phases of Underground Construction

Figure 3 shows several phases of underground facility construction.

1) First, horizontal boreholes are created to access an area with optimum geological properties.
2) Then, those boreholes are widened.
3) The next phase is drilling horizontal boreholes to connect those shafts.

4) The horizontal boreholes are widened.
5) Several parallel horizontal boreholes are drilled at a defined distance.
6) The horizontal boreholes are widened by removing the material between the tunnels at certain places. These places alter from tunnel to tunnel in order to maintain the stability of the construction. Using this technique, the first underground facility of about 3000m^2 is created. At the same time, borehole drilling for facility no. 2 is carried out.
7) Widening of boreholes for facility no. 2, drilling boreholes for facility no. 3.
8) Widening of boreholes for facility no. 3, drilling boreholes for facility no. 4.
9) Widening of boreholes for facility no. 4, drilling boreholes for next phases of construction (level below, at the same level).

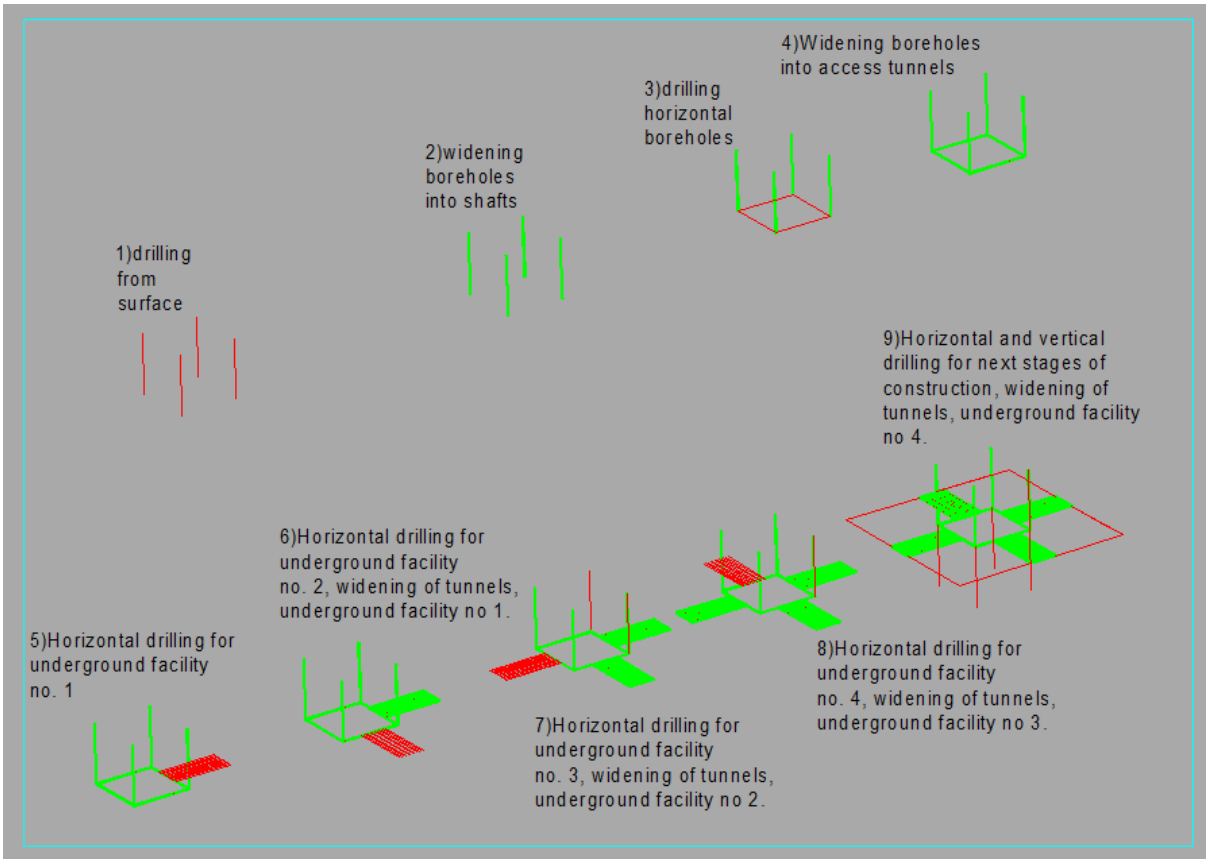

Figure 3. Phases of underground construction

The table below shows what resources would be needed at each phase of this type of construction. The first column shows the phase and the second shows the number of days after the start of the construction. The third and fourth columns show the number of equipment pieces used in each phase, for drilling and widening equipment respectively. The final three columns show the amount of material excavated in cubic metres.

Phase	After days	Drilling equipment	Widening equipment	Material excavated (boreholes)	Material excavated (widening)	Material excavated (all)
	no.	pcs	pcs	m^3	m^3	m^3
1	50	4	0	3.14	0	3.14
2	200	0	4	0	2822.86	2826.00
3	250	4	0	3.14	0	2829.14
4	400	0	4	0	2822.86	5652.00
5	450	12	0	9.42	0	5661.42
6	600	12	12	9.42	8468.58	14139.42
7	750	12	12	9.42	8468.58	22617.42
8	900	12	12	9.42	8468.58	31095.42
9	1050	12	12	9.42	8468.58	39573.42

6. Conclusions

The structure detailed above offers 4 underground facilities measuring 100m x 50m, each with an area of about 5000m^2, including pillars. All together, the structures would cover an area of about 20,000m^2, which could be used for living, working or other activities. Less than 40,000m^3 must be excavated in order to create that much area underground, meaning this process is very effective.

Theoretically, all this could be done with 12 pieces of both drilling and widening equipment, which would weigh 3.6 tons according to our assumptions regarding equipment weight. More realistically, and taking into account maintaining material like drilling heads, we would potentially need hundreds of tons of equipment. This would have to be brought from Earth. However, some parts could be also produced on site, using 3D printing or other techniques, or from local materials. This could change the situation rapidly. The locations used for such facilities would need to be carefully chosen, as the geological conditions would need to be as good as possible.

1050 days theoretically means less than 3 years. Realistically, this would probably be a 10-year project, or longer. There should be an established tent-based settlement in existence prior to the start of construction, as this proposal should be considered as a second stage development of settlements on other planets.

Literature:

- NASA scientists studying pictures from the Odyssey spacecraft have spotted what might be seven caves on the flanks of the Arsia Mons volcano on Mars. The pit entrances measure from 100 to 252 metres (328 to 827 ft) wide and they are thought to be at least 73 to 96 metres (240 to 315 ft) deep. the pits have been informally named (A) Dena, (B) Chloe, (C) Wendy, (D) Annie, (E) Abby (left) and Nikki, and (F) Jeanne. Dena's floor was observed and found to be 130 m deep. Further investigation suggested that these were not necessarily lava tube "skylights". Review of the images has resulted in yet more discoveries of deep pits. It has been suggested that human explorers on Mars could use lava tubes as shelters. The caves may be the only natural structures offering protection from the micrometeoroids, UV radiation, solar flares, and high energy particles that bombard the planet's surface. These features may enhance preservation of biosignatures over long periods of time and make caves an attractive astrobiology target in the search for evidence of life beyond Earth.
- Deep underground concept: https://deeepunderground.com/underground.html
- CONCEPT EVALUATION OF MARS DRILLING AND SAMPLING INSTRUMENT (Matti Anttila, Helsinki University of Technology, Laboratory of Space Technology, Espoo, March 2005)

Deep underground project

https://deeepunderground.com/

https://join.deeepunderground.com/