cSc

# Design Concepts for Pressurized Lunar Shelters Utilizing Indigenous Materials

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Concept 1
- Cast basalt cylindrical segments; held together w/ long. tensile cables.
- No end closures, ingress, egress, windows, etc.
- Requires clamps/jacks to final assembly.

Option 2
- arch slabs
- 4-sided w/ tension strands.

Notes
- not much has been done here. Most of the work is in the future.
- should consider tunneling & emplacement.
- should develop tools (K.C. Park)

Third Annual Symposium
November 21 & 22, 1991

N93-26414



A NASA Space Engineering Research Center at the University of Colorado

## Structural Design Concepts for Pressurized Lunar Shelters Utilizing Indigenous Materials:

John Amin Happel, Kaspar Willam, Benson Shing

### 1. Design Objective:

Pressurized shelter built of indigenous lunar materials

### 2. Scope:

a.) Structural Design w/ Lunar Conditions

b.) Review of Previous Concepts

c.) Selection of Indigenous Material

d.) Design Variables

e.) Design 1: Cylindrical Segments

f.) Design 2: Arch-Slabs with Post-Tensioned Ring Girders

### 3. Lunar Conditions Which Impact Design:

**Primary Factors:**

* High Vaccuum;

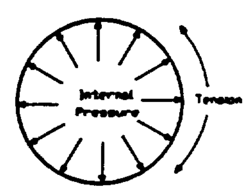
<u>Pressure vessels</u>

Tension loads

Primary design load

1 atm. pressure = 1440 psf load, terrestrial loads ≈ 150 psf

100 ft. (30.5m) of regolith to balance pressure load

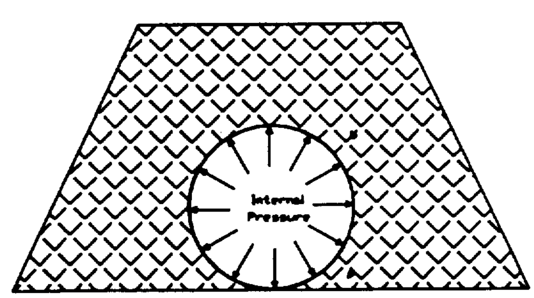



* High Radiation;

<u>Radiation shielding required</u>

15 ft. (4.5m) regolith (or more?)

Regolith excavation

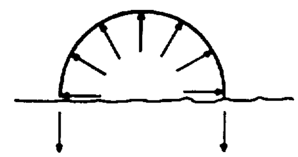


* Poor Soil Conditions for Anchoring Foundations;

  Regolith depth > 16ft (5m) most locations

  Tension anchors difficult

  <u>"floating" structures</u>



* Very Remote Site;

  Setup & resupply expensive

  <u>Indigenous materials permit rapid expansion</u>

  Safety

  Speed & Simplicity

**Secondary Factors:**

Meteoroids (impact damage)

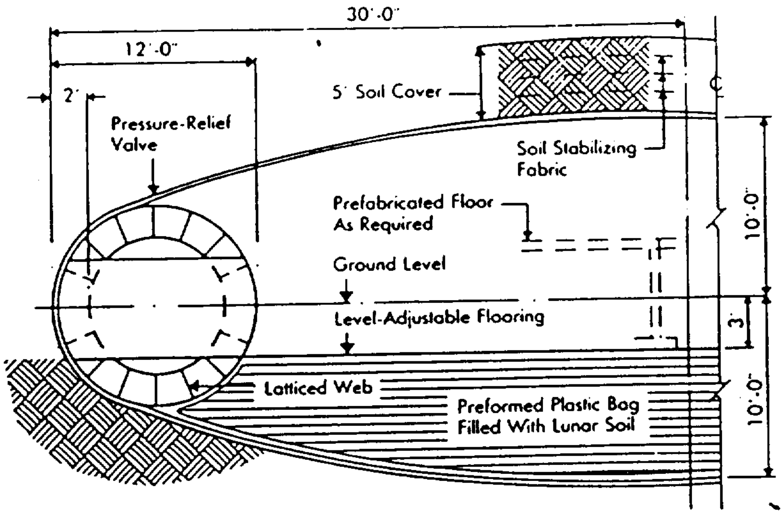
Low Gravity (construction)

Long Days and Nights (construction)

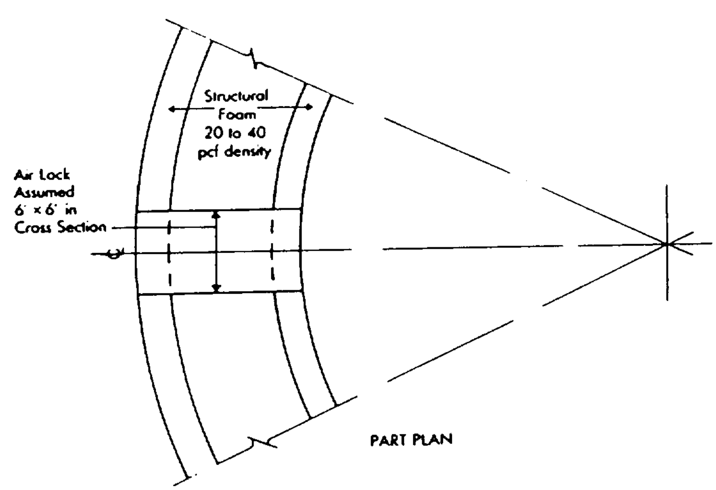
Extreme Temperatures (sealants)

# 4. Review of Previously Proposed Concepts:

*Chow, P.Y., Lin, T.Y. ;  T.Y. Lin Assoc.; 1989




CROSS SECTION




PART PLAN

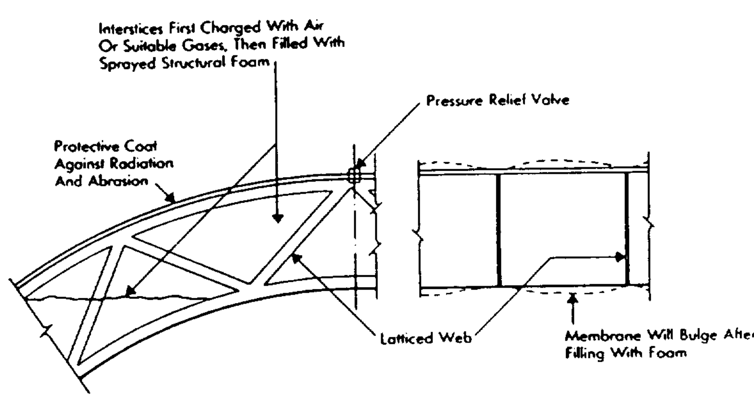
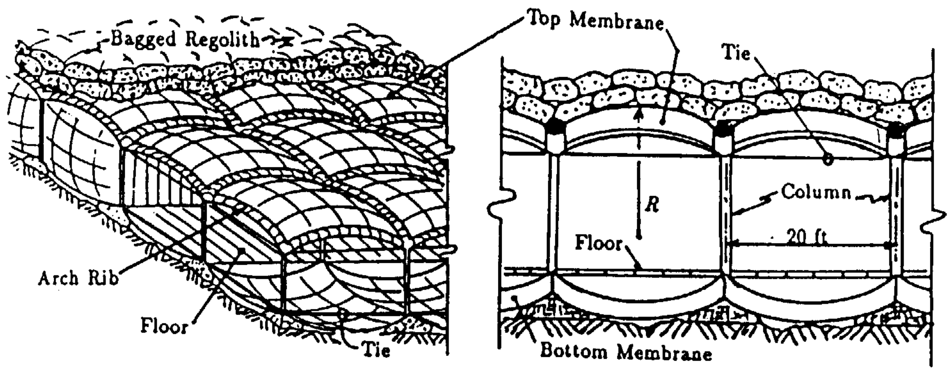



**FIG. 3. Wall Construction and Latticed Web Details**

**FIG. 1. Pressurized Self-Supporting Membrane Structure (PSSMS)**

*Vanderbilt, M.D., Criswell, M.E., Sadeh, W.T.; C.S.U.; 1988




(a) Cutaway of Structure

(b) Section Through Interior

Figure 2. Cutaway and Section of Structure

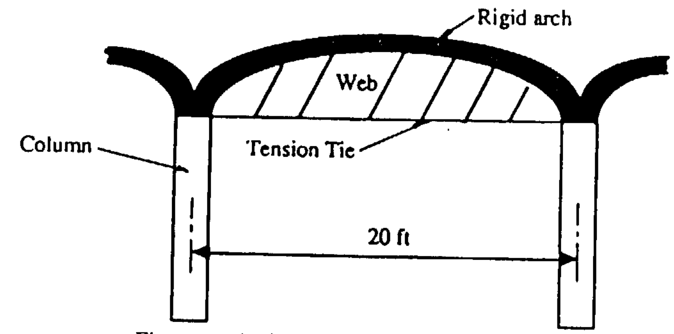
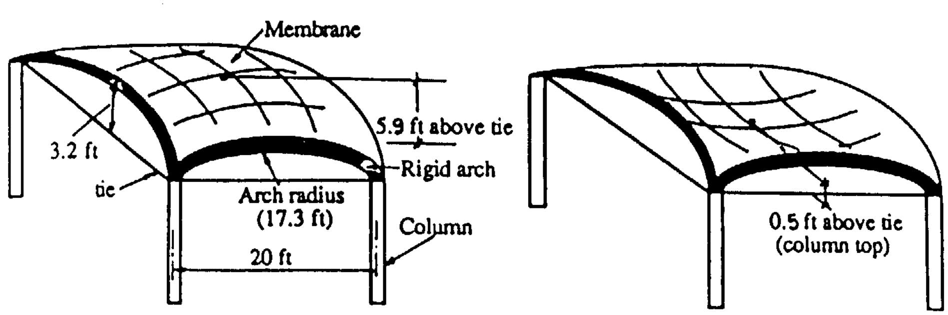



Figure 5. Arch Rib System with Web




Inflated Shape

Deflated Shape

Figure 3. Arched Membrane System

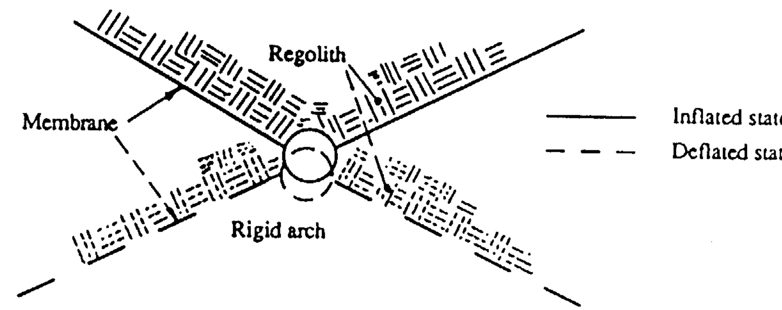



Figure 4. Cross Section of Arch Rib

*Yin, P.K., NASA 90 Day Study; 1990

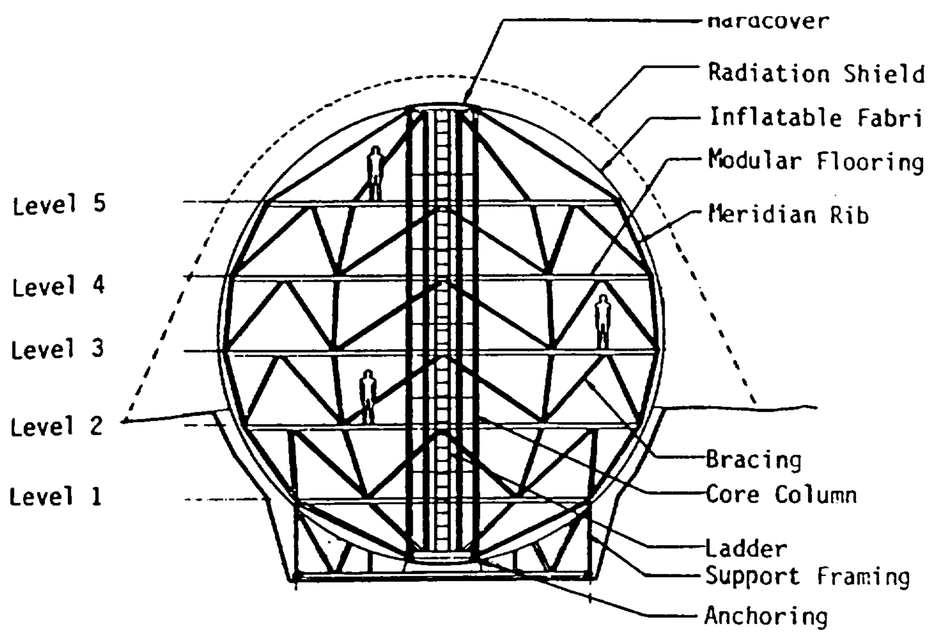



Figure 1. - Elevation

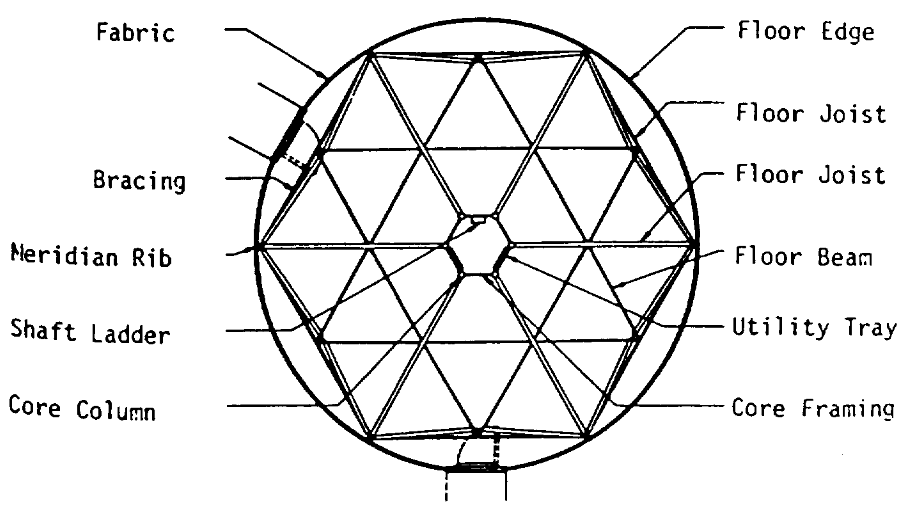
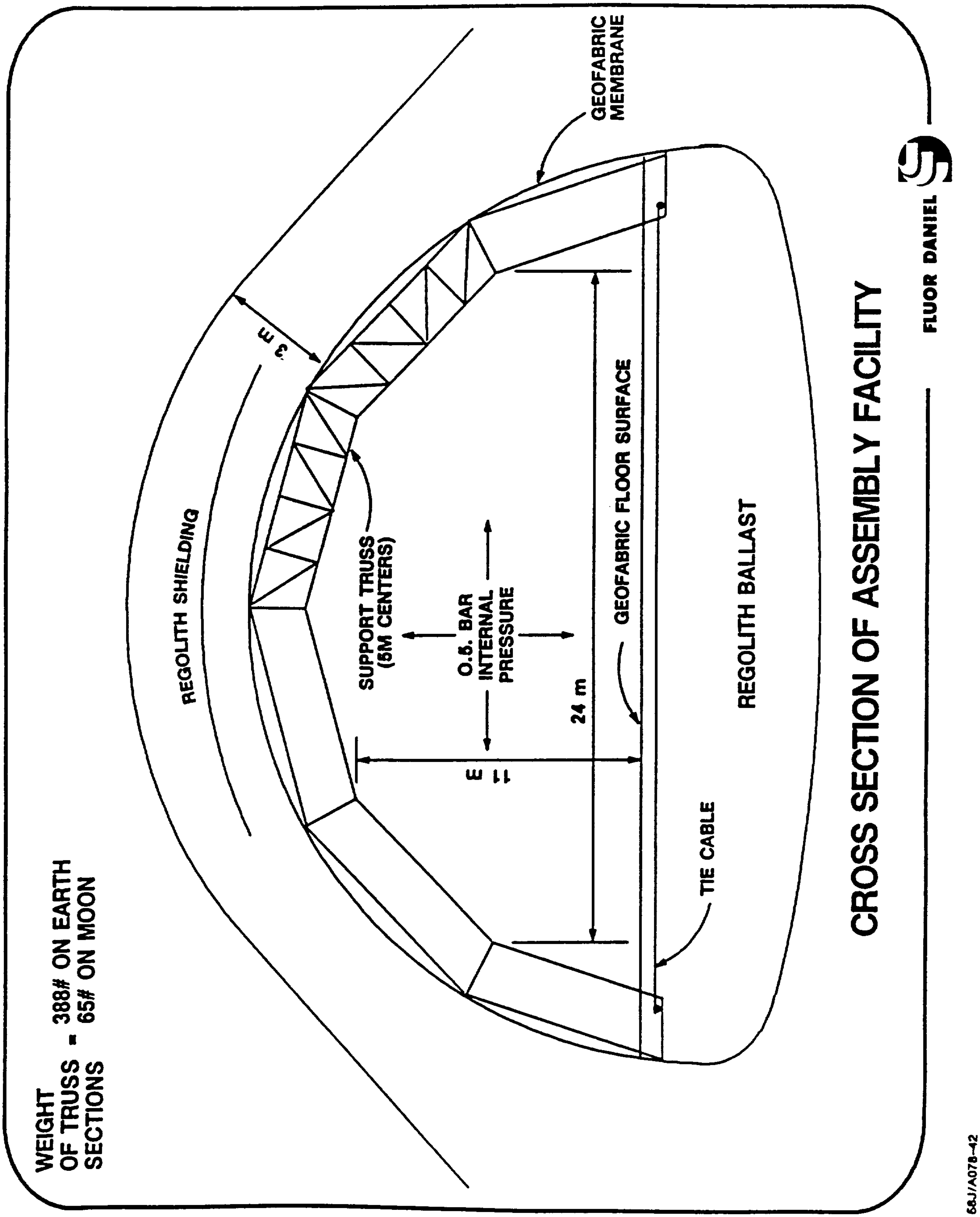



Figure 2. - Typical Framing Plan

*Richter, P.J., Drake, R.M.; Fluor Daniels; 1990




CROSS SECTION OF ASSEMBLY FACILITY

5. **Rationale for Indigenous Materials:**

* Large structures need large quantities of materials

* Permits rapid growth and expansion of activities;

    Reduces shipping costs

    Reduces time

* Ship high tech equipment not structural mass

6. **Indigenous Material Choices:**

* Fused and Sintered Regolith, Bricks and Blocks;

    Easy to manufacture

    Low strength, highly heterogenous material properties

* Lunar Glasses and Glass-Glass Composites;

    High strength

    Very promising still experimental

* Lunar Concrete;

    Raw materials for aggregrate and cement available

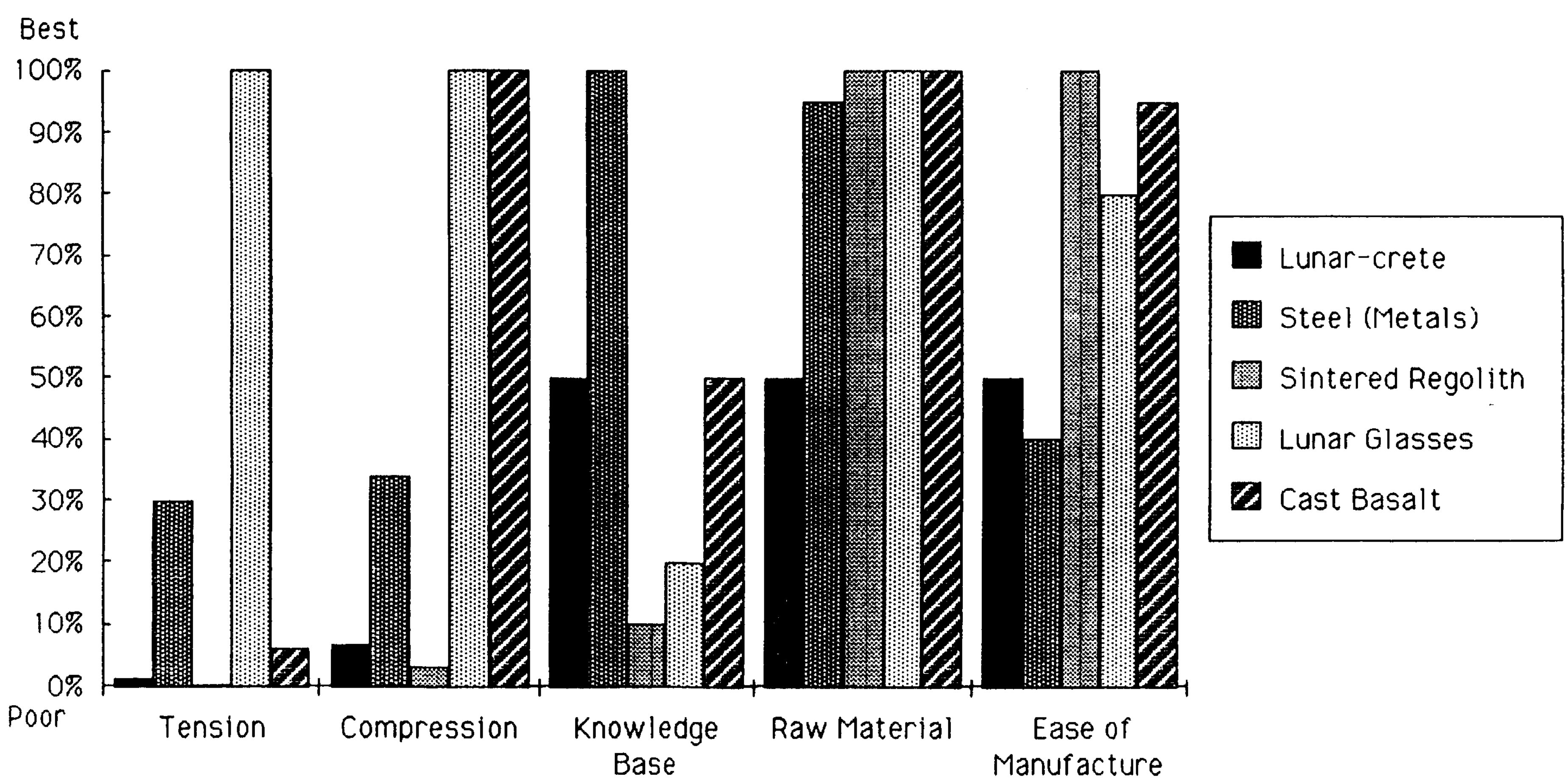
    Mechanical properties well understood

* Steel and other Structural Metals;

    Excellent mechanical properties

    Complicated, multi-step manufacturing process

## Material Selection



* Cast Basalt;

One step manufacturing process

Good mechanical strength properties

<u>Selected as primary construction material</u>

7. **Cast Basalt Properties:**

Tensile strength: $f_t$= 34.5 MPa (5,000 psi);

Compressive strength: $f_c$=538 MPa (78,000 psi);

Modulus of elasticity: E=100 GPa (14E6 psi);

Fracture toughness: Kc= 2 MPa$\sqrt{m}$ , +/- 50%

Mass density: 3 g/cm$^3$ (specific lunar weight= 31.2 lunar lb/ft$^3$).

Melting point: 1300°C

8. **Design Variables:**

* Shelter sizing;

  large enough to contain Space Station Freedom modules

* Loading conditions;

  Internal pressure=10 psi (0.069 MPa)

  Regolith shielding depth= 15 ft (4.5m)

* Constraints imposed by cast basalt;

  Brittle:

    Low tensile stresses

    Compression should dominate structure

    Post-tensioning

  Material hardness

  Maximum volume of single component= 70.6 $ft^3$ (2 $m^3$)

    Determined by casting process

* Maximum moveable weight= 1,670 lunar lbs (44.5 kN)

* Minimize use of imported materials;

  Minimize tensile reinforcement

* Self-equilibrating structure;

  Tensile loads self-contained

  No arches, vaults, or domes

* Minimize excavation

## 9. Design One, Cylindrical Segments:

### Dimensions:

Diameter= 23 ft (7m)

Wall thickness=3 in. (7.6 cm)

Total length= 60 ft (18.3m ), forty segments

Segment length= 1.5 ft. (46 cm)

Floor thickness= 8 in. (20 cm)

Leg width= 15 in. (38 cm)

Segment mass ≈ 2200 lunar lbs (6000 kg)

### Design Features:

*Positive;

Pre-cast floor

Passage for utilities

Rapid assembly

Readily expandable

Only three components

Minimal use of reinforcing

Efficient

*Negative;

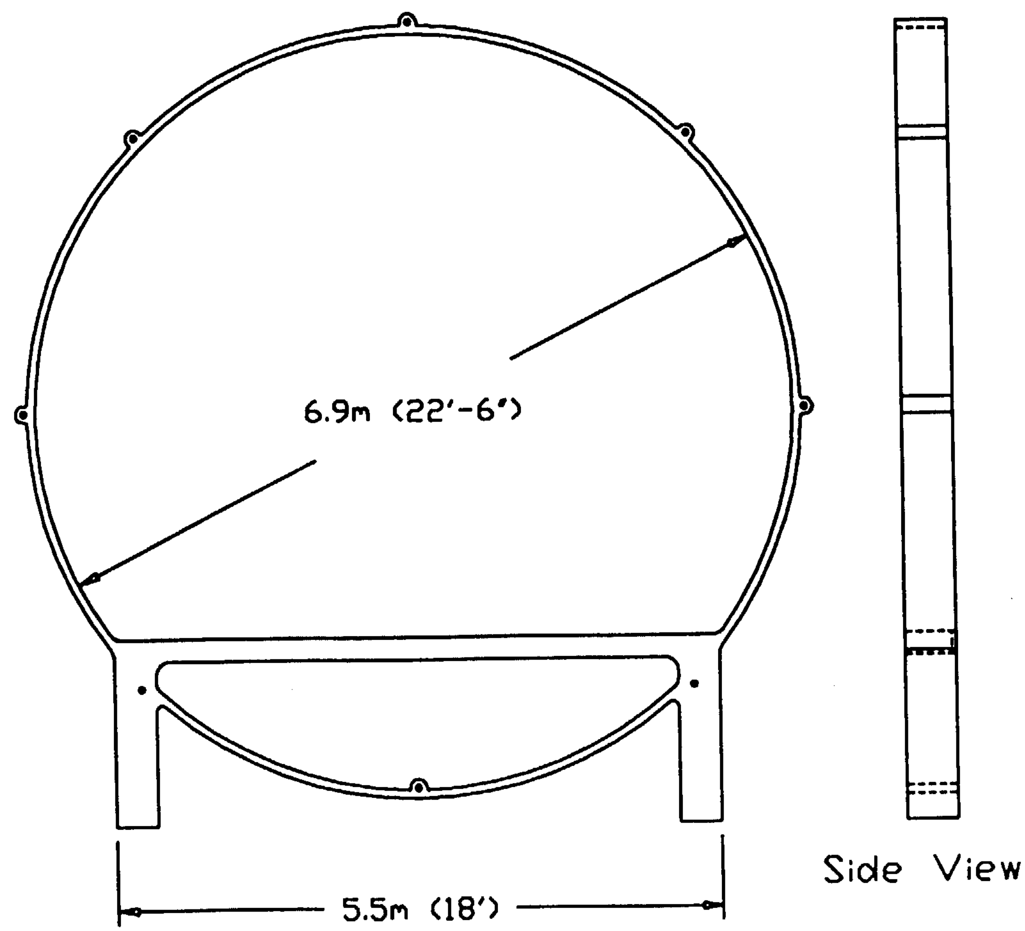
Feasibility of casting basalt into large structural elements

a.) under lunar conditions

b.) mold design

Uncertain crack and notch sensitivity of cast basalt

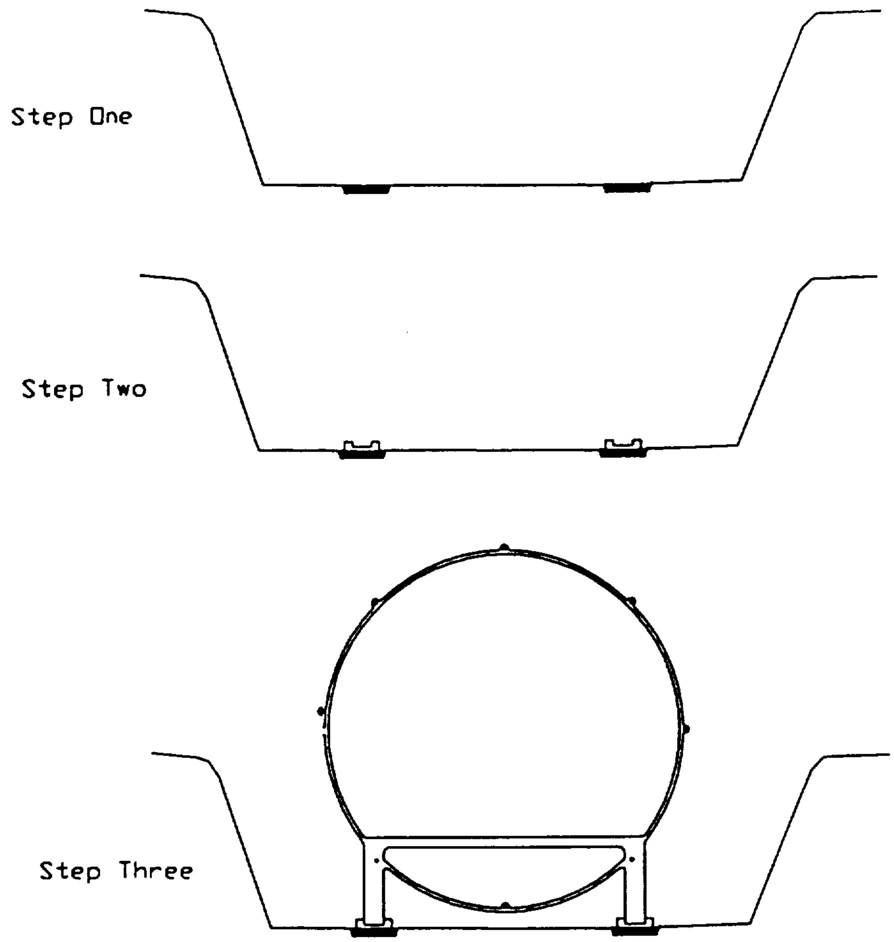
CAST CYLINDRICAL SEGMENT



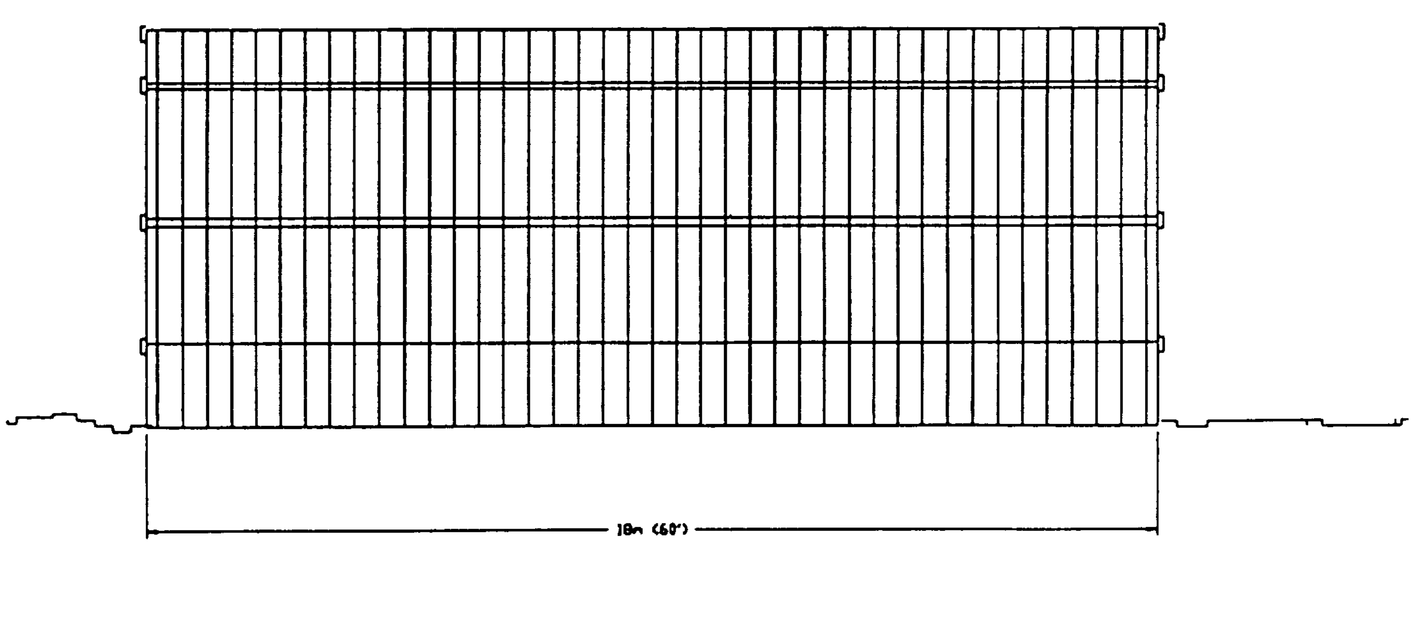
## Construction Sequence:

1. Cast 40 segments, 2 end caps
2. Smooth site, area= 33 x 60 ft (10 x 18m)

   or excavate a flat-bottomed trench, depth ≈ 6.5 ft. (2m)
3. Place two long guide-rail beams
   - a.) cast in segments
   - b.) cast in place
4. Align rail sections and bolted together
5. Place first cylindrical segment
   - a.) Insert eight tendons into ducts
   - b.) Install the gasket material
6. Place following segment on rails
   - a.) advance tendons through the current segment
   - b.) repeat steps 5 & 6 until the last segment is in place
7. Install end caps
8. Post-tension tendons to pull entire structure tightly together
9. Pressurize structure
10. Bury the structure
11. Fit out interior with partitions and utilities




## Assembled Base



## 10. Design Two, Arch-Slabs with Post-Tensioned Ring Girders

**Dimensions:**

* Overall Dimensions;

Height= 18 ft (5.5m), Width = 23 ft (18m)

Length= 60 ft.(18m)

*Slab Dimensions;

Span= 76 in (193 cm), Edge thickness≈ 10 in (25 cm)

Center thickness≈ 3 in (7.6 cm)

*Girder Dimensions;

Span= 25 ft (7.6m), Width= 7 in (17.8 cm)

Center depth= 36 in ( 91.5 cm), End depths= 12 in (30.5 cm)

**Design Features:**

*Positive;

Compression dominated

Inherently safe design

Crack growth limited

Components utilize simpler molds

Orthogonal expansion

All surfaces flat

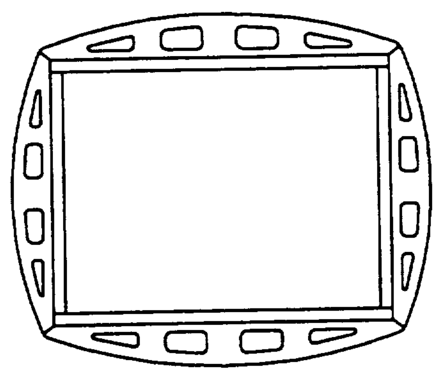
*Negative;

Greater number of cast pieces

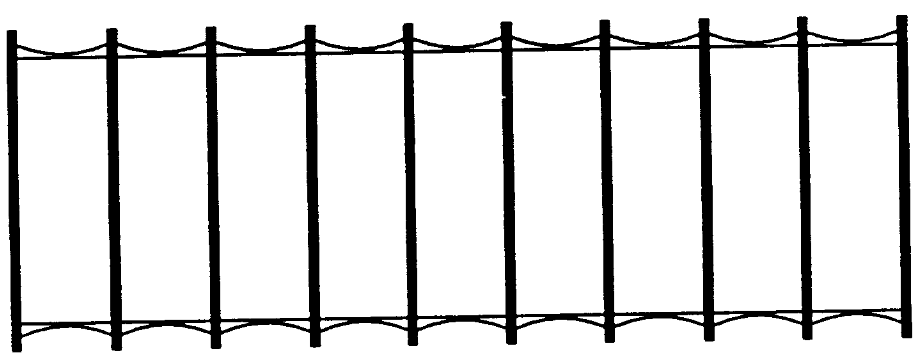
More complicated construction sequence

Much more reinforcement material needed

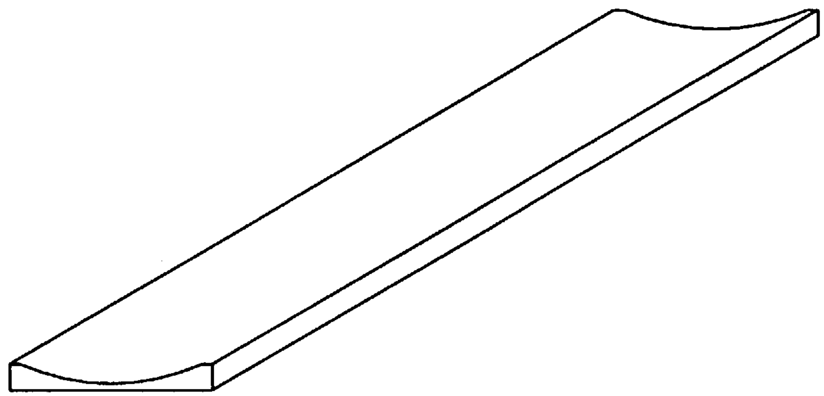
# Archslabs With Post-Tensioned Ring Girders



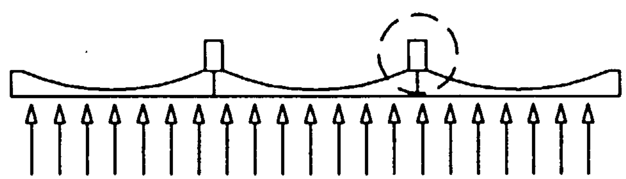
End View

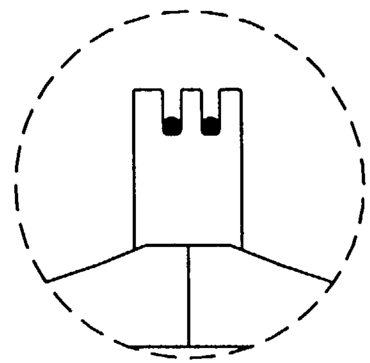


Side View



Archslab Component





Girder-Slab Joint

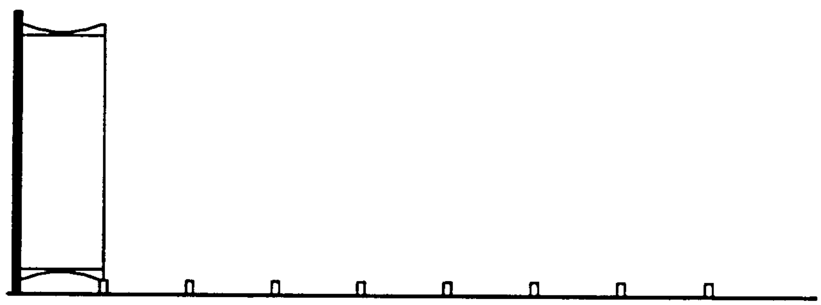
## Construction Sequence:

1. Cast; 36 arch-slabs, 40 girders, 2 end caps
2. Level site
3. Place first 2 floor girders
   a.)lay tendons beneath,
   b.)set slab between them
   c.) repeat nine times
4. Place end cap in position and brace
5. Install 2 opposing wall slabs,
   a.) set ceiling slab on top
6. Install first complete ring girder set
   a.) wrap tendons around girder set
   b.) post-tension first two tendons
7. Repeat steps (5.) and (6.) nine times
8. Install final end cap
9. Install and post-tension longitudinal tendons
10. Pressurize
11. Bury
12. Fit out interior

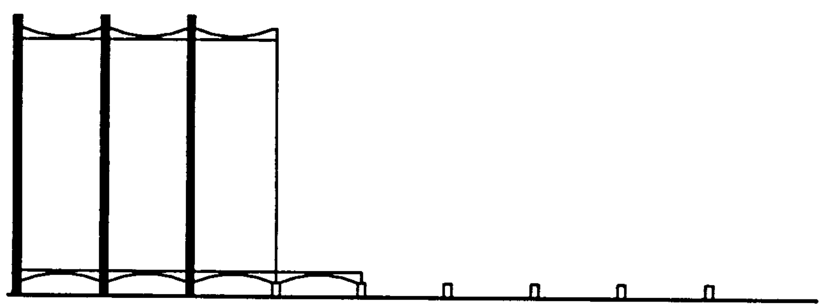
# Construction Sequence

Steps 1 to 3

Steps 4 to 6



Step 7 (etc.)



## 11. Future Research:

* Mechanical properties of cast basalt;
    - a.) fracture toughness & notch sensitivity
    - b.) distribution of tensile strength values

* Feasibility of casting basalt into large structural elements

* Gasket material and design

* Additional design(s) under consideration;
    - a.) evaluate three designs
    - b.) select one for detailed design and testing

* Develop FE predictive model for full stress analysis of final concept

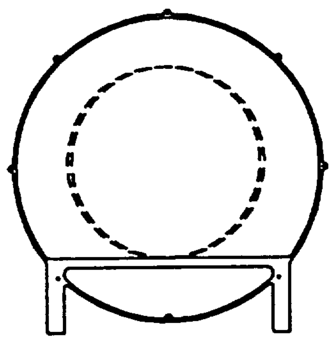
* Build and test 1/6 scale model in laboratory utilizing cast basalt or simulant materials

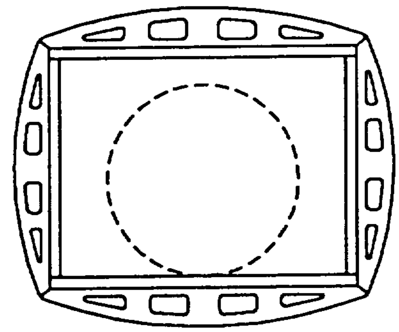
## 12. Conclusions:

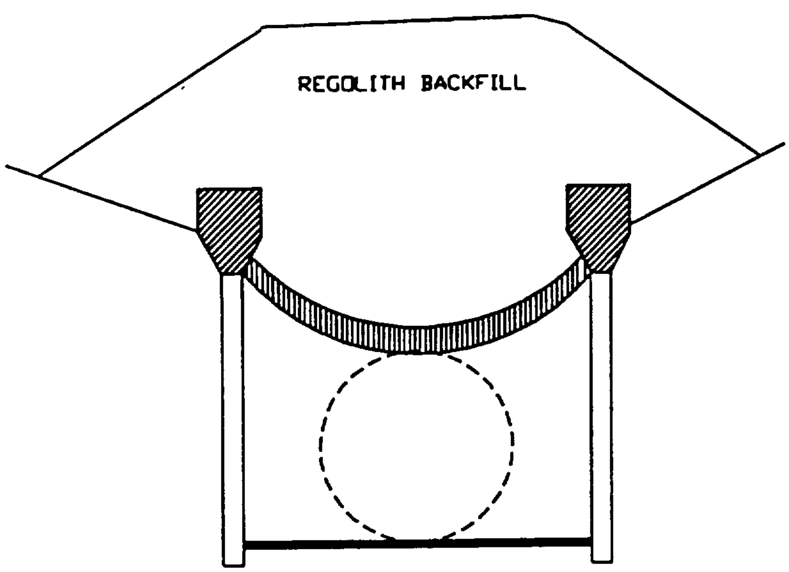
1.) Cast basalt selected

2.) Several designs are feasible

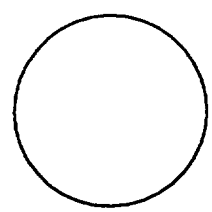
3.) Additional research needed








INVERTED COMPRESSION ARCH



Space Station Freedom
Module Cross Section

⇒ Develop <u>tools</u>