# Tunneling for the Supergrid

Supergrid II, October 25, 2004

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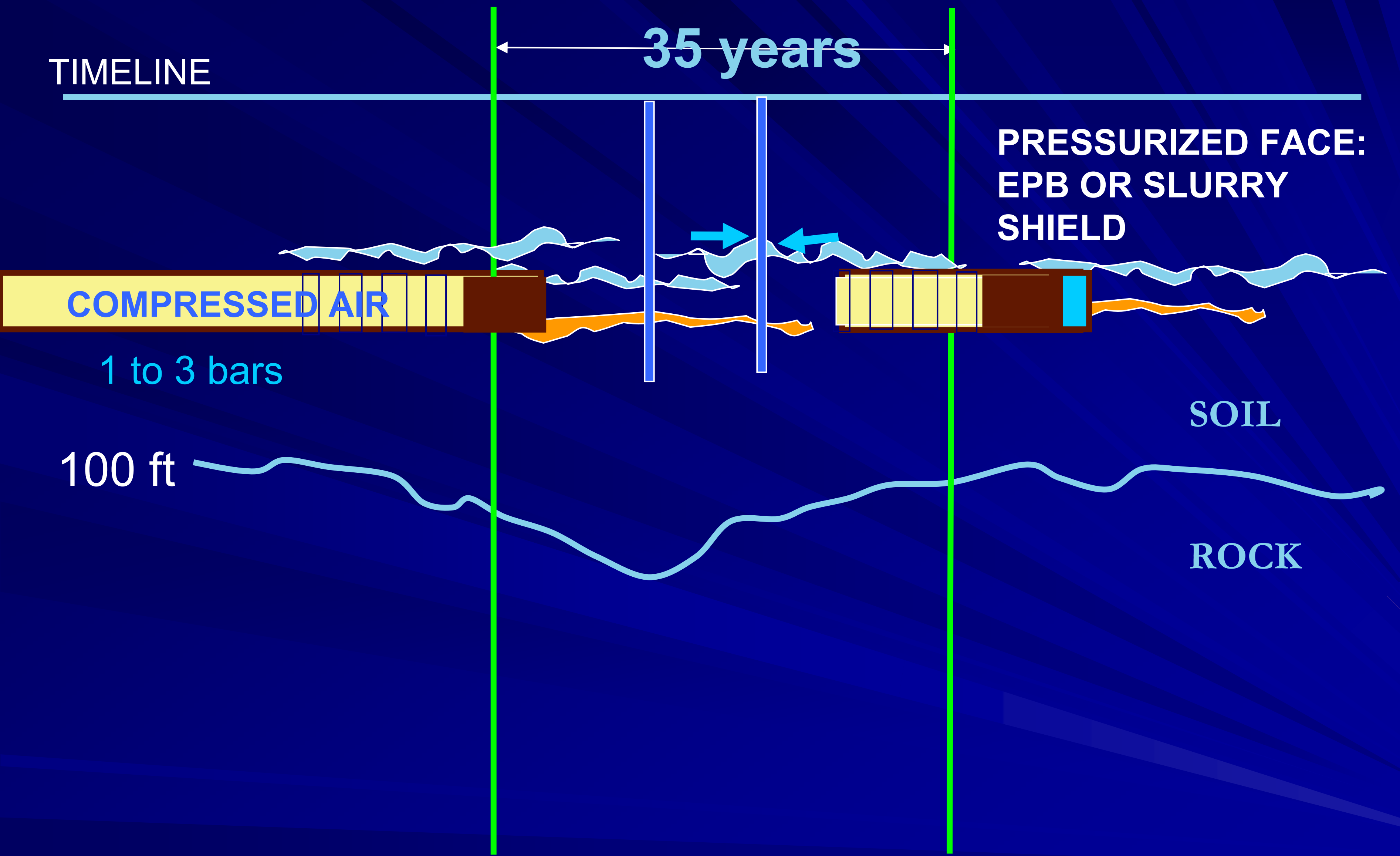
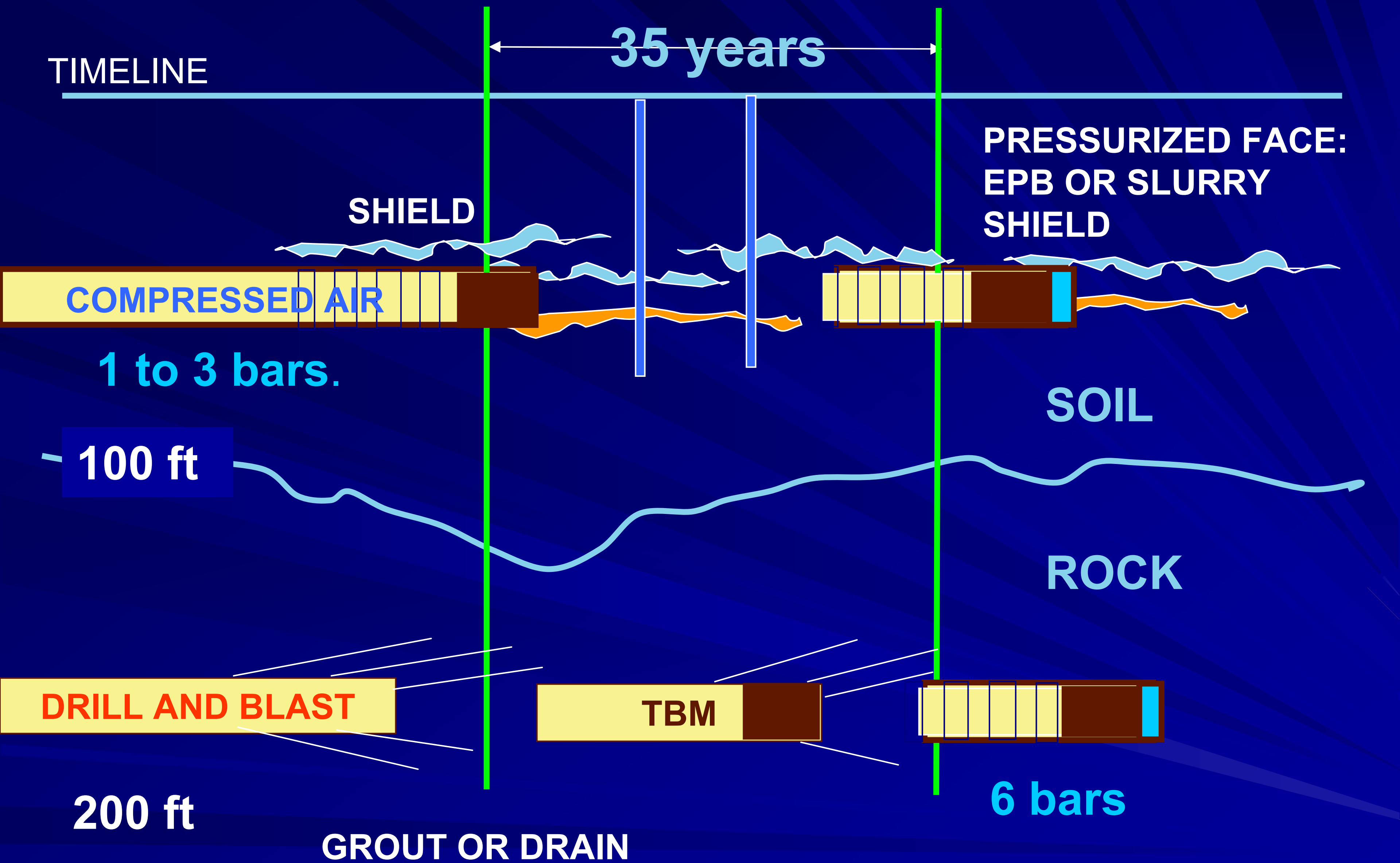

TIMELINE
35 years
PRESSURIZED FACE:
EPB OR SLURRY
SHIELD
COMPRESSED AIR
1 to 3 bars
SOIL
100 ft
ROCK



35 years
TIMELINE
PRESSURIZED FACE:
EPB OR SLURRY
SHIELD
SHIELD
COMPRESSED AIR
1 to 3 bars.
SOIL
100 ft
ROCK
DRILL AND BLAST
TBM
6 bars
200 ft
GROUT OR DRAIN

# Supergrid facilities

- Power generation
  - Nuclear plants underground: technology exists: 100-ft-wide + caverns. Find good rock
- Transmission lines
- Distribution line connections
  - Electrical
  - Hydrogen
- Mechanical
  - Coolant plants
  - Hydrogen-electrical exchangers
- Service, maintenance access

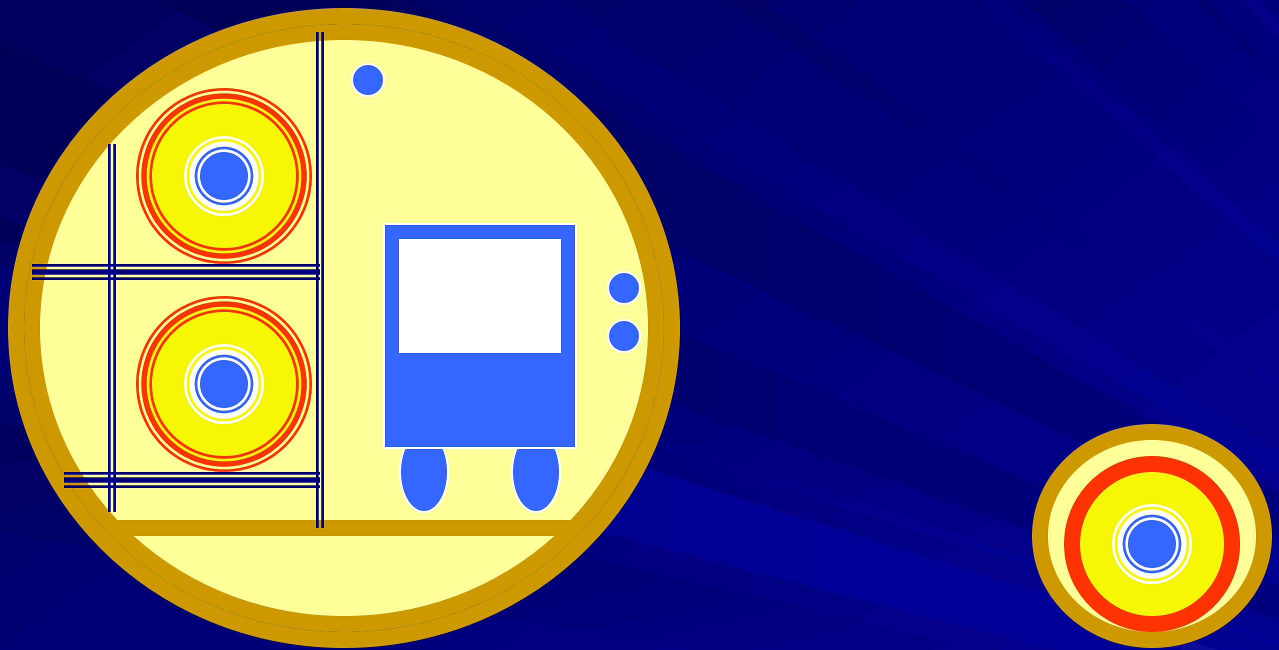
# Super conducting mainline:

- Length of line between stations (distribution points or mechanical access points).
- Tunnel access for:
  - Maintenance
  - Replacement of sections of the line.
- Tunnel size alternatives
  - Single cable
  - Personnel access
  - Single cable and replacement cable installation
  - Two operating cables
  - Additional space for mechanical lines – coolant.
- Stations: shafts or laterals
  - Distribution lines
  - Mechanical support: cooling plants

# Requirements

- Redundancy
  - Multiple lines in a single tunnel
  - Multiple tunnels and lines (grid)
- Security
  - Controlled access
  - Hardened: adequate depth
  - Location uncertainty
  - Redundancy
- Access for maintenance, repair, replacement while tunnel is operating
- Access for replacement cable
  - Curvature,  Length
- Replacement after shutdown?: pulling cable.
- Tunnel environment
  - Leakage  - Drainage – Humidity - Temperature

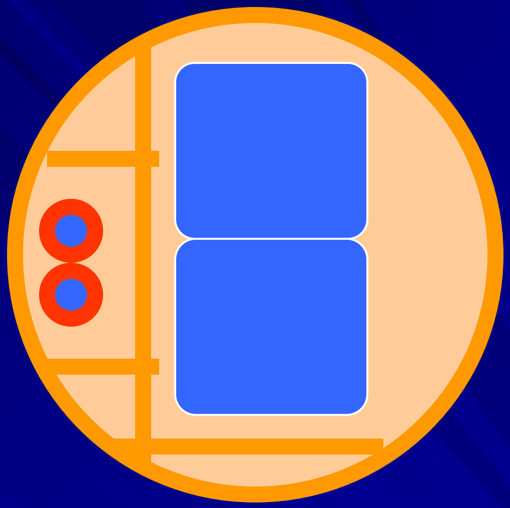
# Tunnel with two cables and access: 10- to 15-ft diameter

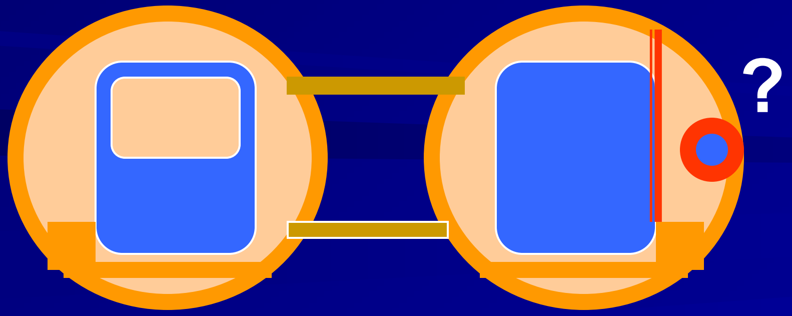


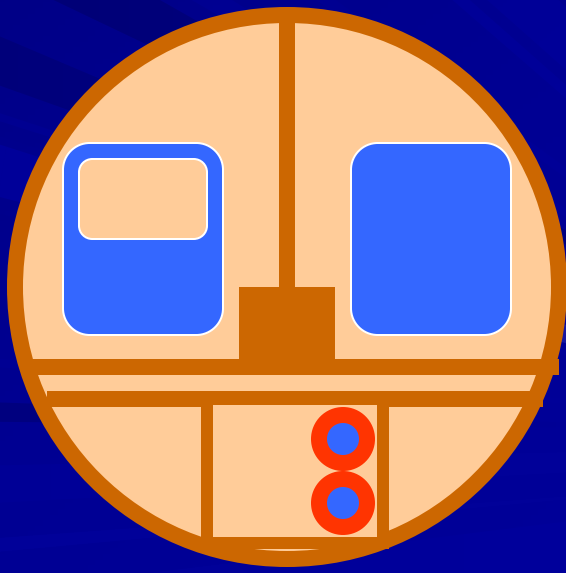
Pipe with single cable pulled through: HDD or micro- tunneling

# Multiple use corridors: large tunnels

- Rail:
  - Freight, double stack
  - Passenger, twin tunnels: 20-ft-dia: limited additional space
  - Passenger, single tunnels: 35-ft-dia
- Fire Life Safety concerns
- High speed corridors: high population density
- Portion of tunnel cost supported by supergrid ? Major cost of mainline is for transportation.





# Tunnel Depth

- Below utilities and foundations
- Below stream beds
- Dependent on frequency and depth of access shafts and laterals
- Dependent on geology
  - Uniform ground conditions are desirable
  - Avoid rock-soil interface
  - Avoid high groundwater pressures
  - Avoid other difficult ground conditions: solution caverns, faults, oil and gas, extremely high permeability zones
  - Advances in TBM technology extend range of ground conditions that can be efficiently tunneled.

# Tunnel Method and Lining

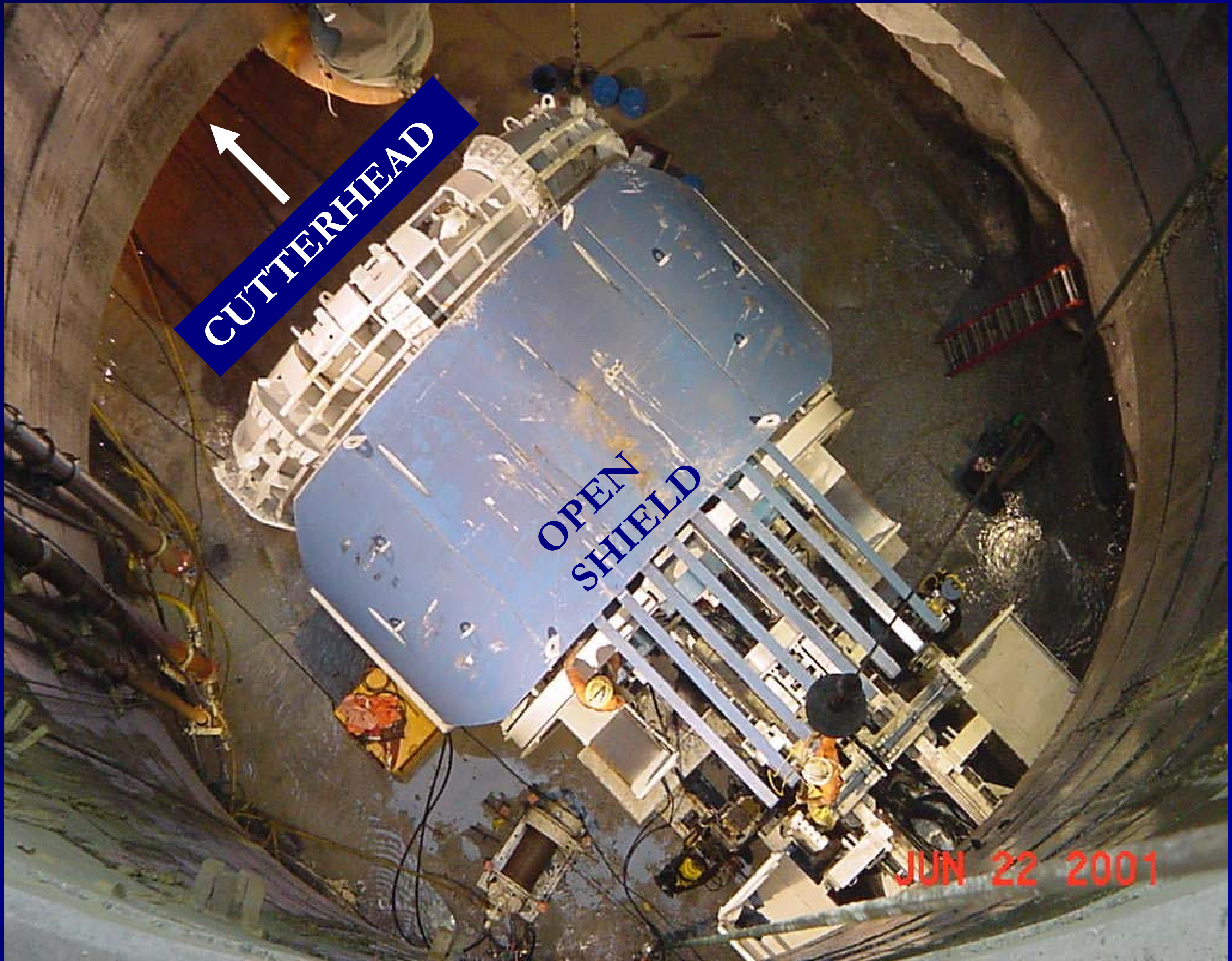
- Short shield tunneling in rock
  - Initial rock bolt support and channels
  - Final lining: cast in place concrete or pipe with grouted backfill
- Shield tunneling
  - Initial lining and final cast in place concrete lining or pipe with grouted backfill
    - Consistent with open shield
  - Segmental concrete lining placed in tail of shield
    - Consistent with EPB or Slurry shield.
- Pipe jacking (Micro-tunneling): (Lining installed in jacking shaft and pushed into the ground)
  - Concrete or plastic pipe sections
    - Consistent with Slurry shield.

# Face support and muck removal

- Open face -- rock
  - Muck removed by conveyor or rail cars
- Pressurized face support
  - Earth pressure balanced shield
    - Muck removed by conveyor or rail cars
  - Slurry shield
    - Muck removed by slurry pipeline
    - Common method for micro-tunneling
    - Also used for larger diameter tunnels

# Drill and Blast

# Chattahoochie Tunnel, Atlanta
## Two 18-ft-dia. tunnel boring machines: 47,000 ft



# Cutter head
# Back-loading (recessed) disk cutters cutting tracks approx. 4 in. apart

DISK CUTTERS

Penetration rate
- - in proportion to
Thrust/cutter & rpm

Thrust:

1960: soft rock

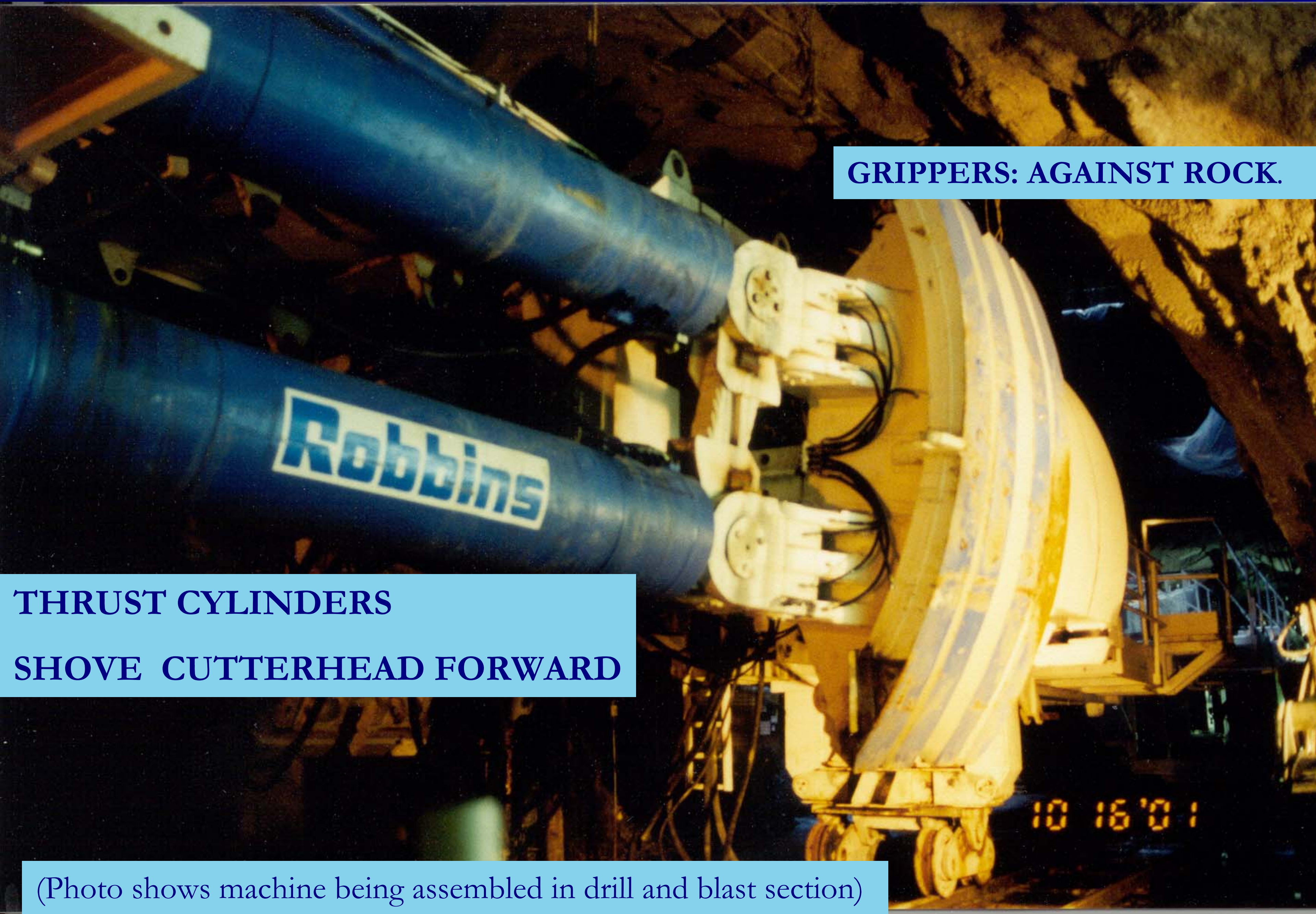
1980: 30,000 lb/ cutter

2000: 70,000 lb /cutter

…the result of improved tool hardness, bearing design & metallurgy.

Advance Rate =
Pen. rate x % Utilization
(% of workday machine is penetrating)

GRIPPERS: AGAINST ROCK.




THRUST CYLINDERS

SHOVE CUTTERHEAD FORWARD

(Photo shows machine being assembled in drill and blast section)


VENTILATION LINE
MINIMUM ROCK SUPPORT:
ROCK BOLTS
CONVEYOR BELT FOR MUCK

# Pressurized face tunnel boring machines

… *now the standard tunneling method for soils that would otherwise flow or run into the tunnel face. Now used in rock. Allows tunneling through water-bearing soils without dewatering.*

- EARTH PRESSURE BALANCED (EPB) SHIELD (*Common for large tunnels in soil)*

Chamber at front of shield is filled with excavated muck mixed with conditioners (foam, polymers, bentonite) to provide a pressure against the face. Muck is removed from chamber with a screw conveyor.

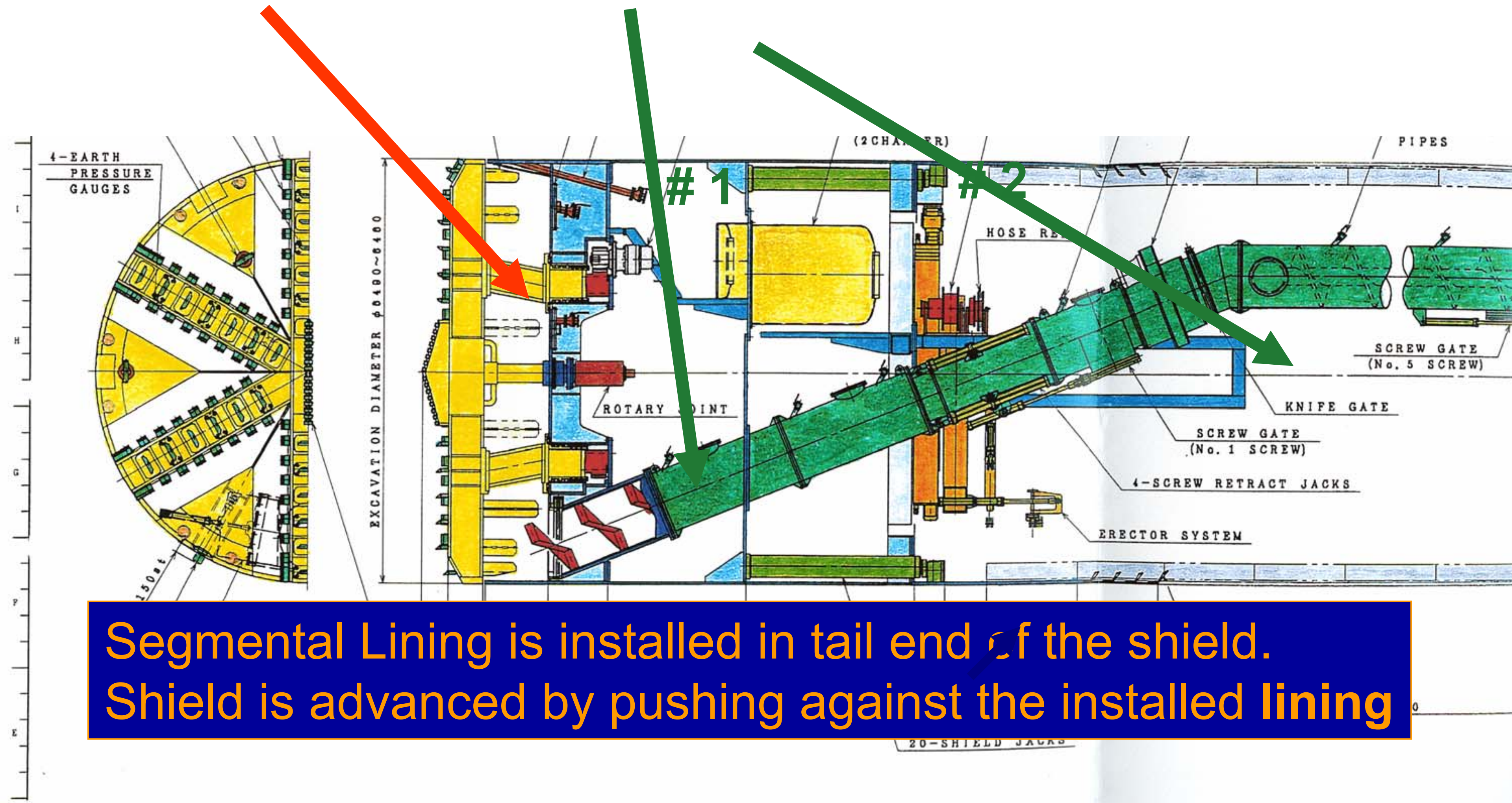
- SLURRY SHIELD *(Common for micro-tunnels)*

Chamber at front of shield is filled with a bentonite slurry mixed with excavated muck to provide a pressure against the face. Slurried muck is removed from chamber and pumped out of the tunnel through a return slurry pipe.

# Earth Pressure Balanced Shield

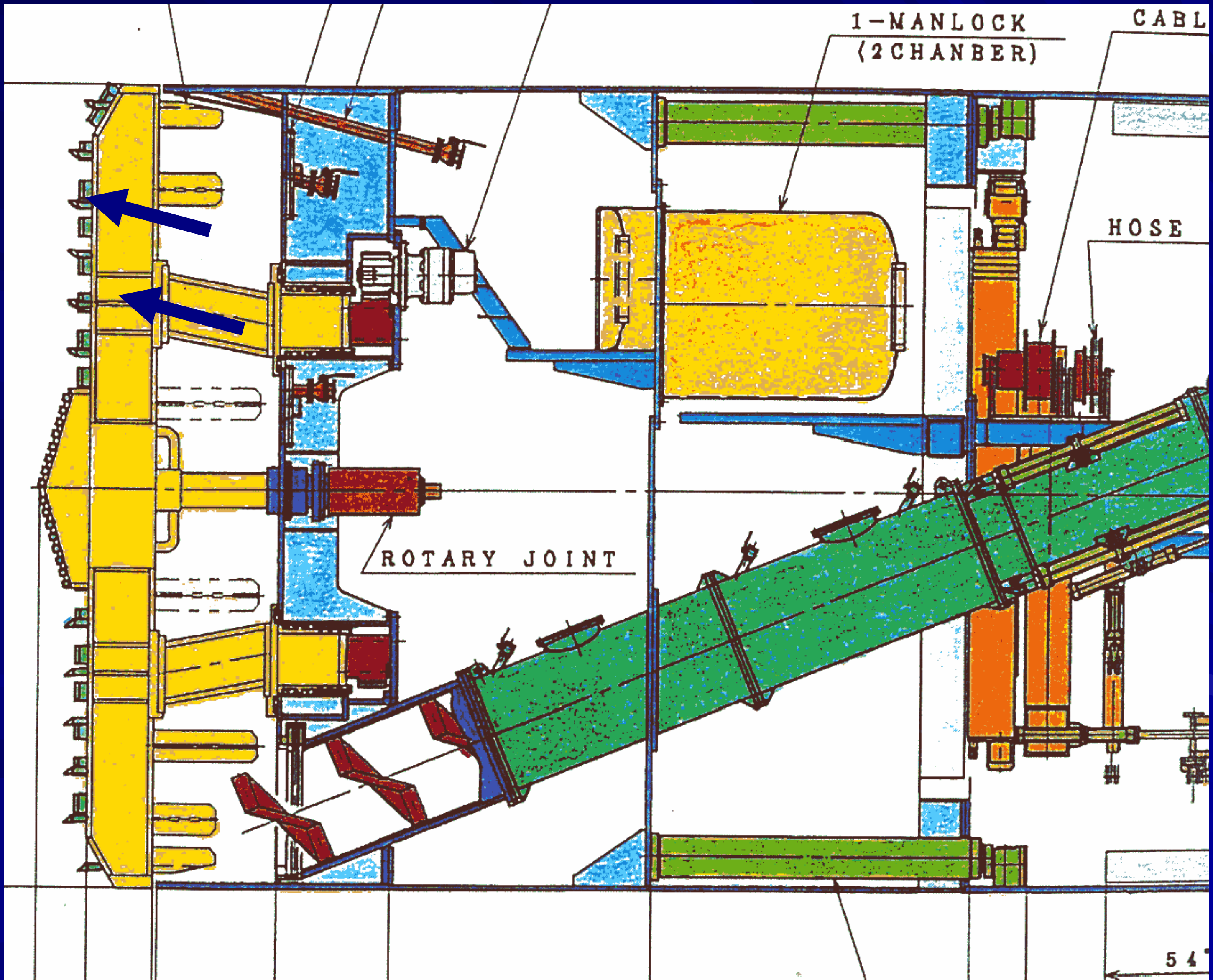
Muck pressurized in chamber supports face

Screws remove muck and provide back pressure

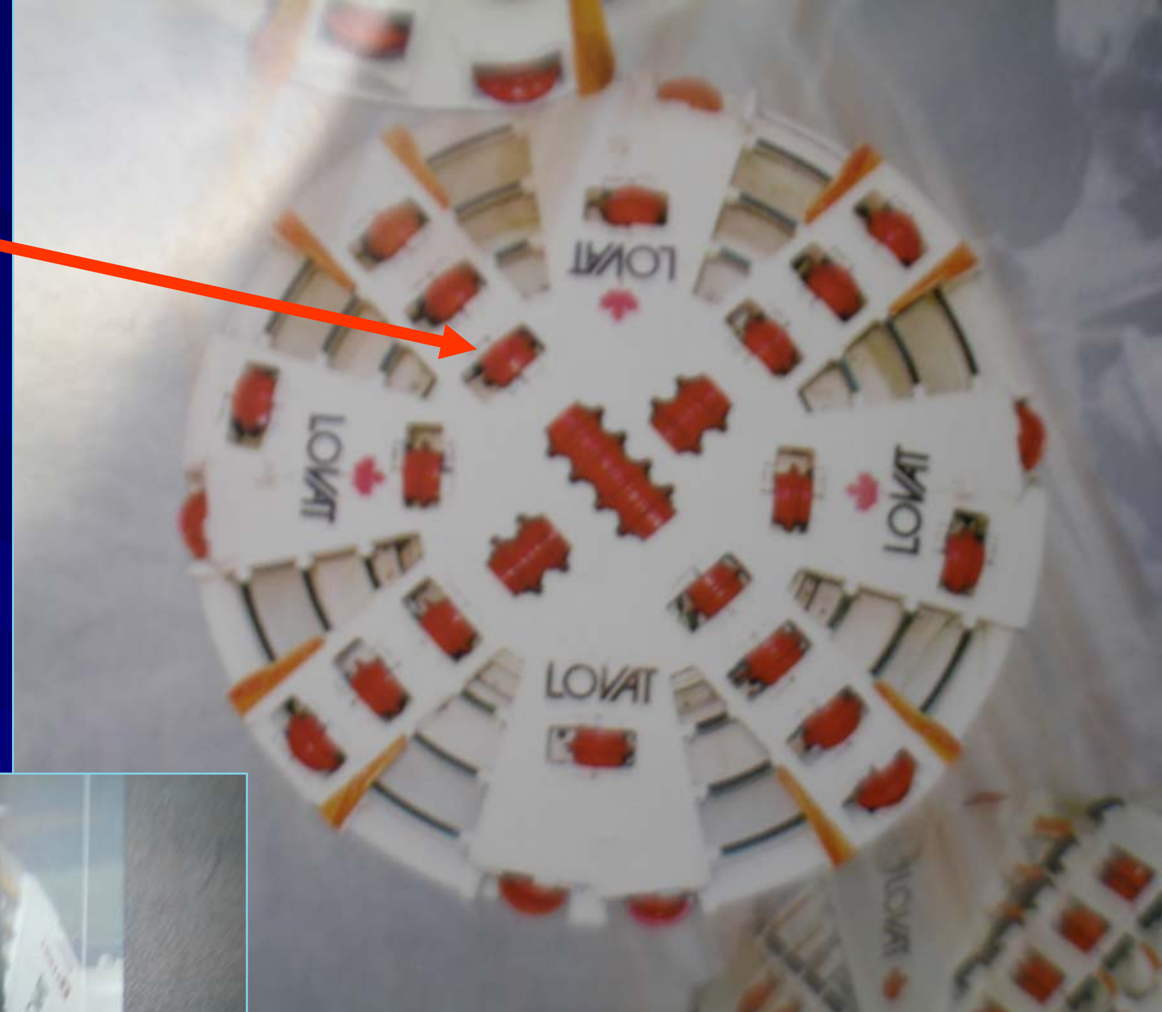



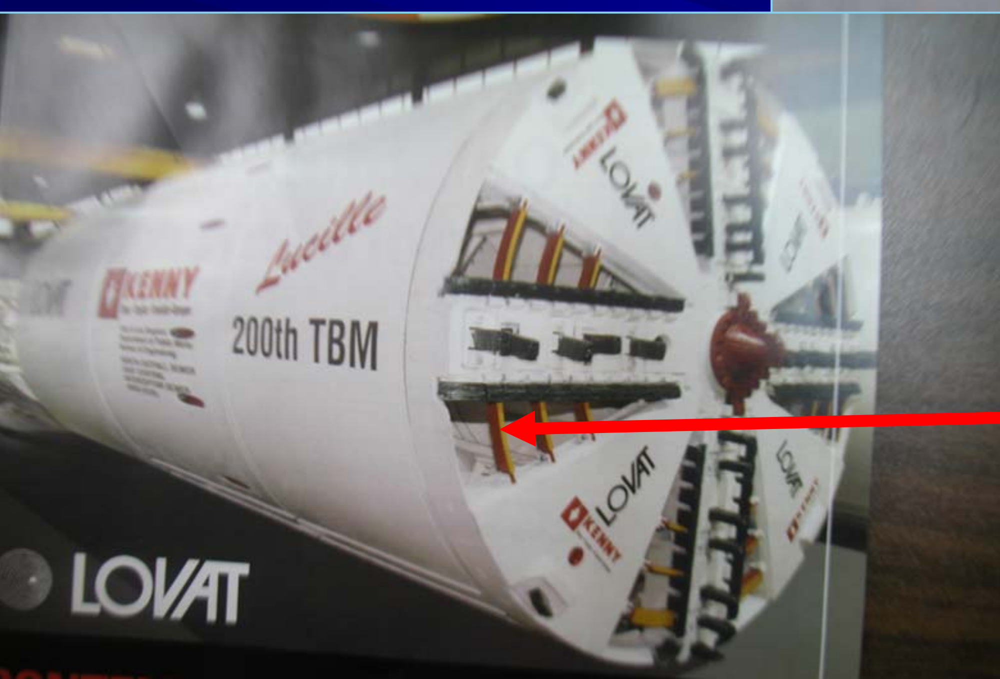

Segmental Lining is installed in tail end of the shield.
Shield is advanced by pushing against the installed **lining**

## Soap foam, polymer is injected to reduce friction and fluidize muck so that face pressure can be developed



Disk cutters to cut boulders, rock



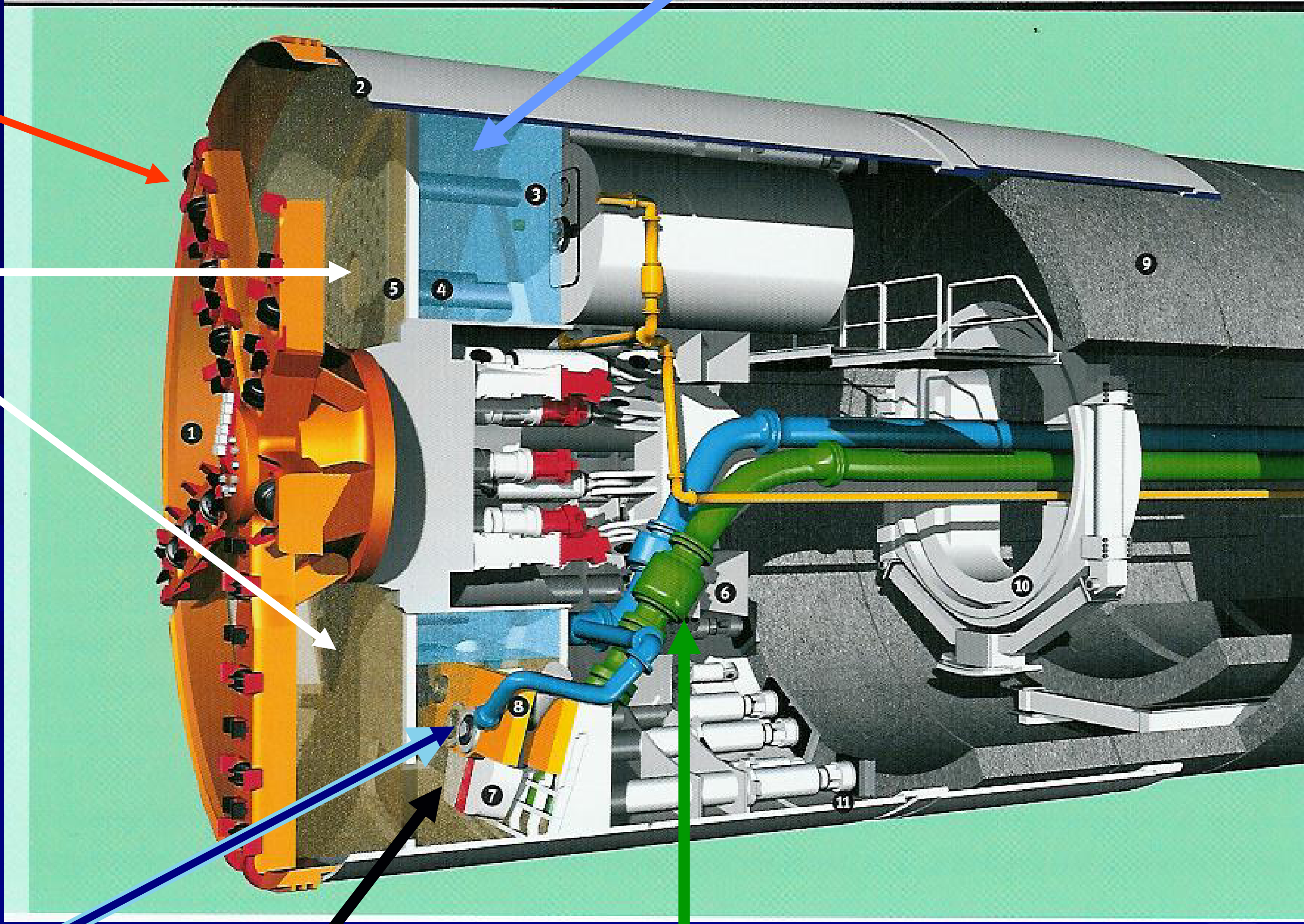

Grizzlies to limit size of boulders passing through the head

# Slurry Shield

1. Cutter wheel with picks

2. Pressurized Chamber, with slurry

3. Compressed Air Cushion

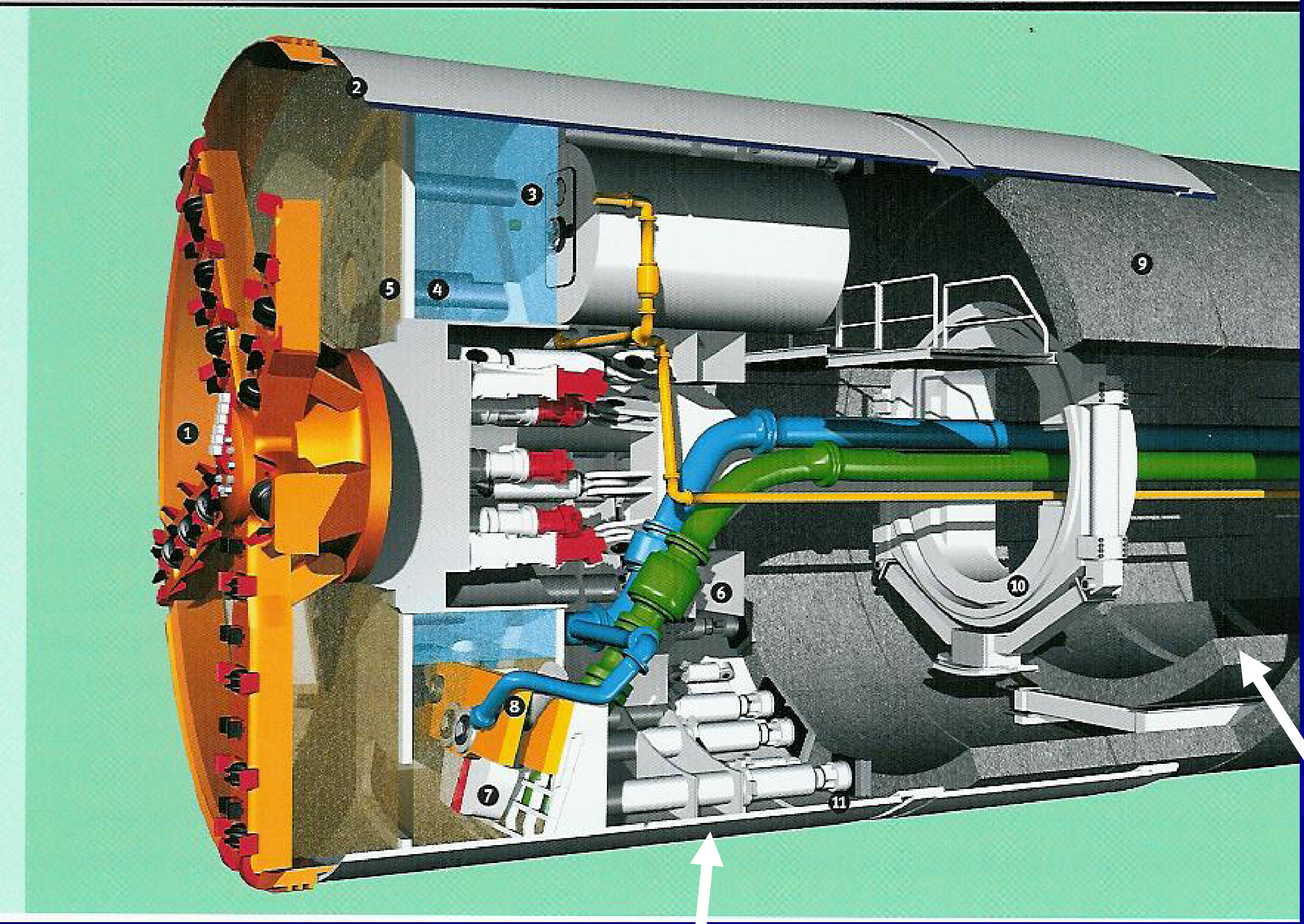



4. Bentonite line into chamber

**5. Stone Crusher**

6. Slurry of bentonite & muck is pumped out of chamber and out of tunnel, then separated

# Slurry Shield




1. Shove jacks to advance shield as wheel cuts ground

2. Concrete segments erected to form a ring, every 4 or 5 ft, after shield is shoved forward.

# MICRO TUNNEL SLURRY SHIELD

- Rotating cutterhead, bentonite slurry supports face
- Slurry is circulated out of tunnel to remove excavated muck
- After muck is separated, slurry is recirculated to tunnel face

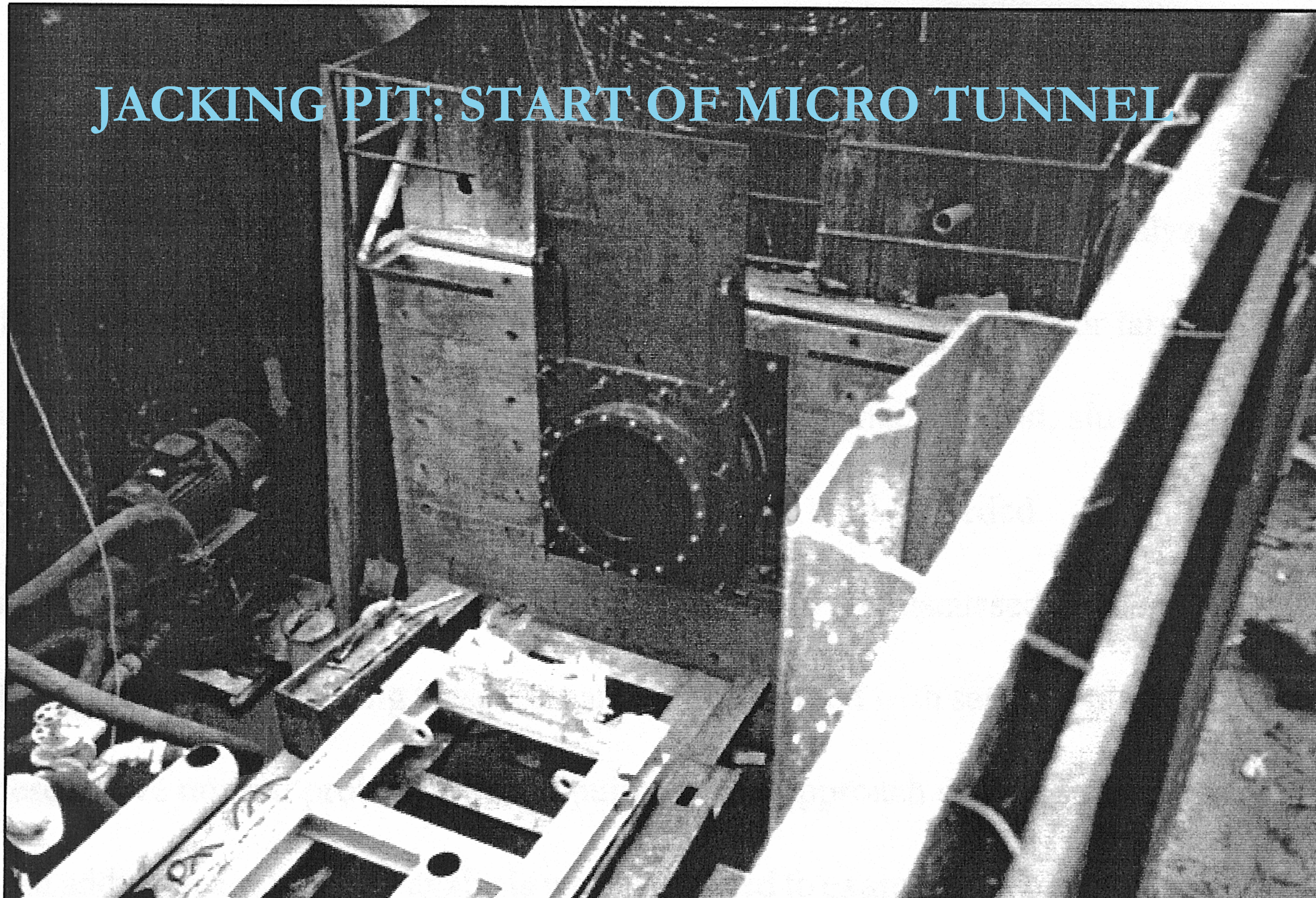
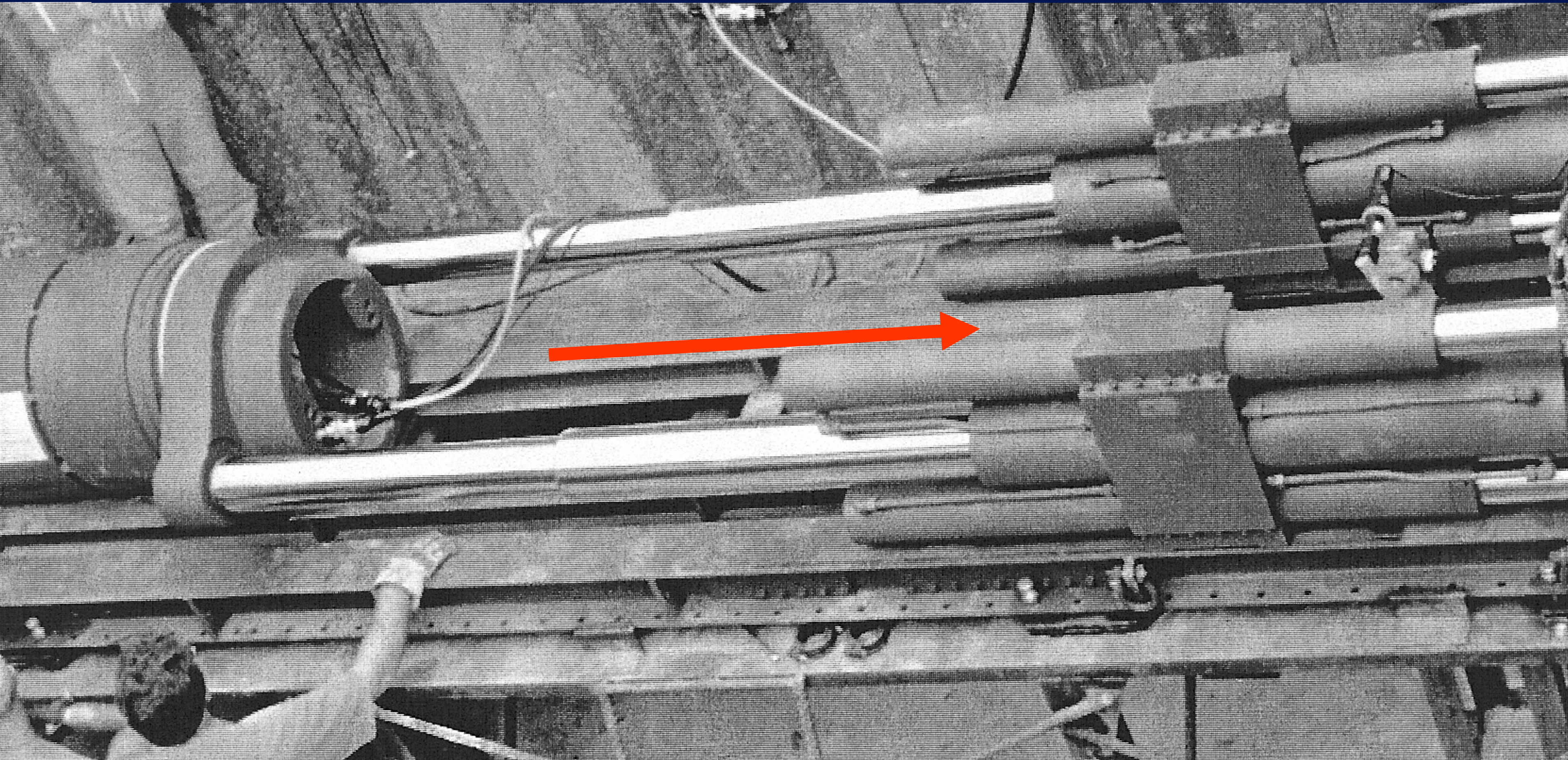


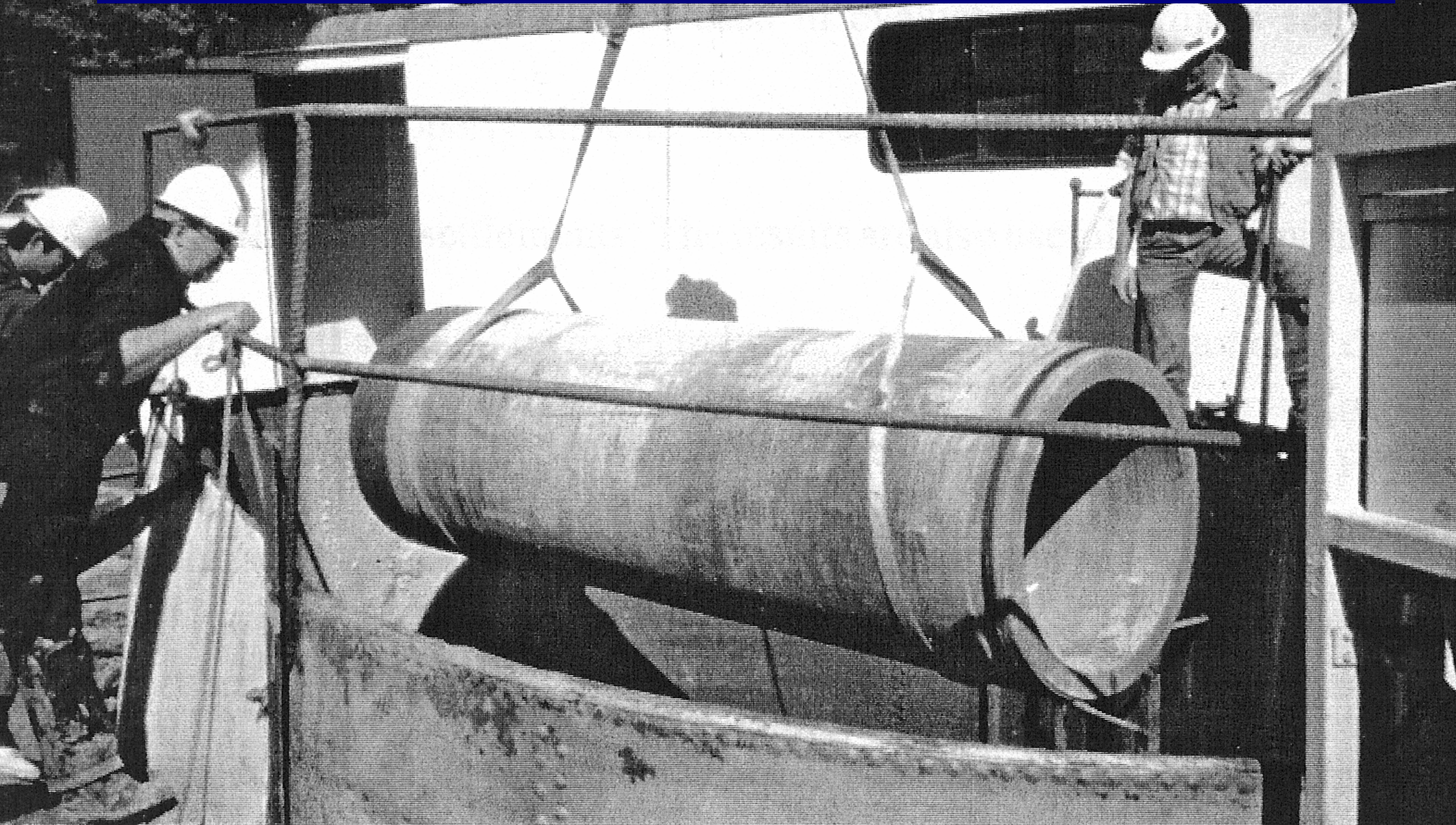

Figure 3.18 Photograph of Double-Entry Ring Seal with Guillotine Closure Used for Retraction and Grouting Tests

# JACKING FRAME IN STARTING PIT

- Place 10 to 12-ft-long pipe, with slurry lines attached
- ~ 30 minutes to install pipe section
- Jack pipe string to advance the shield



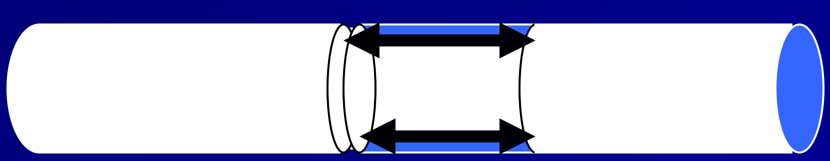
# LOWERING PIPE SECTION INTO PIT FOR JACKING



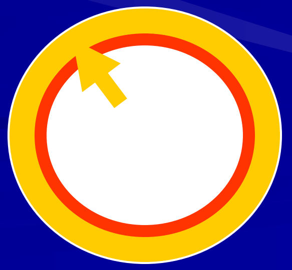
gure 3.19 Concrete Pipes Used for Retrievable Machine Reaming Driv

# Pipe jacking (micro-tunneling)

- Small crew or no crew in tunnel
- Straight runs or very large radius curvature
- Short runs (300 to 1000 ft)
- Additional length achieved with:
  - Access and multiple ports along pipeline for injecting bentonite and floating the pipe
  - Intermediate jacking stations inserted in pipe string: earthworm motion

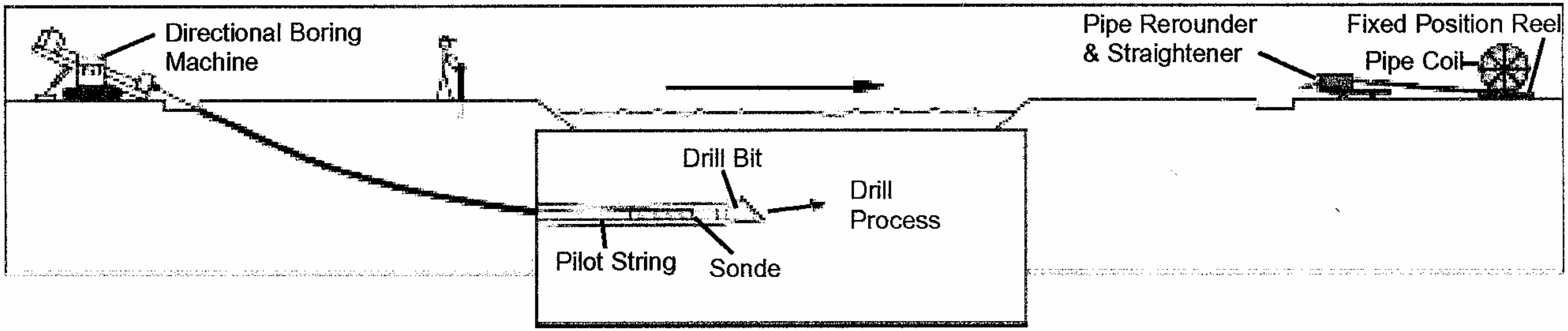


Pump bentonite into annulus

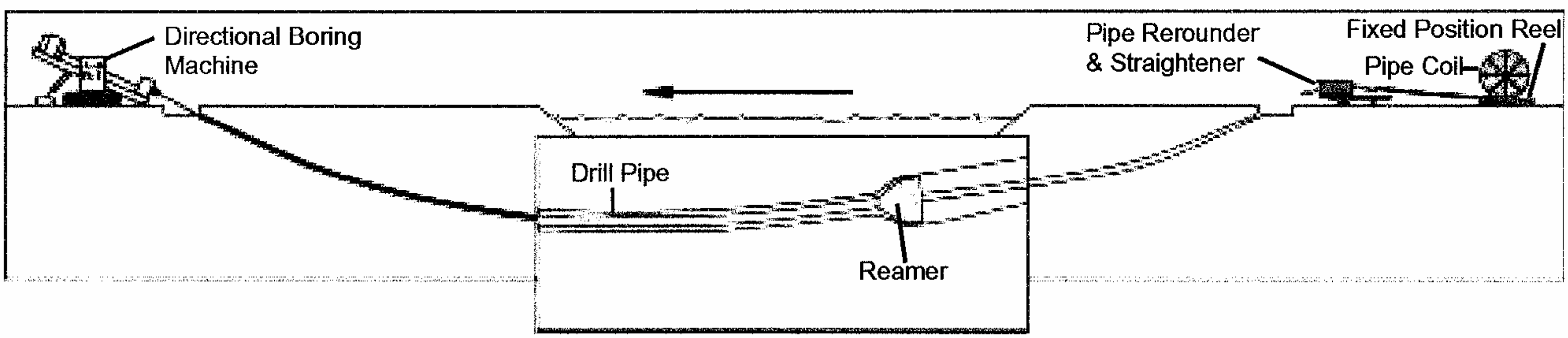


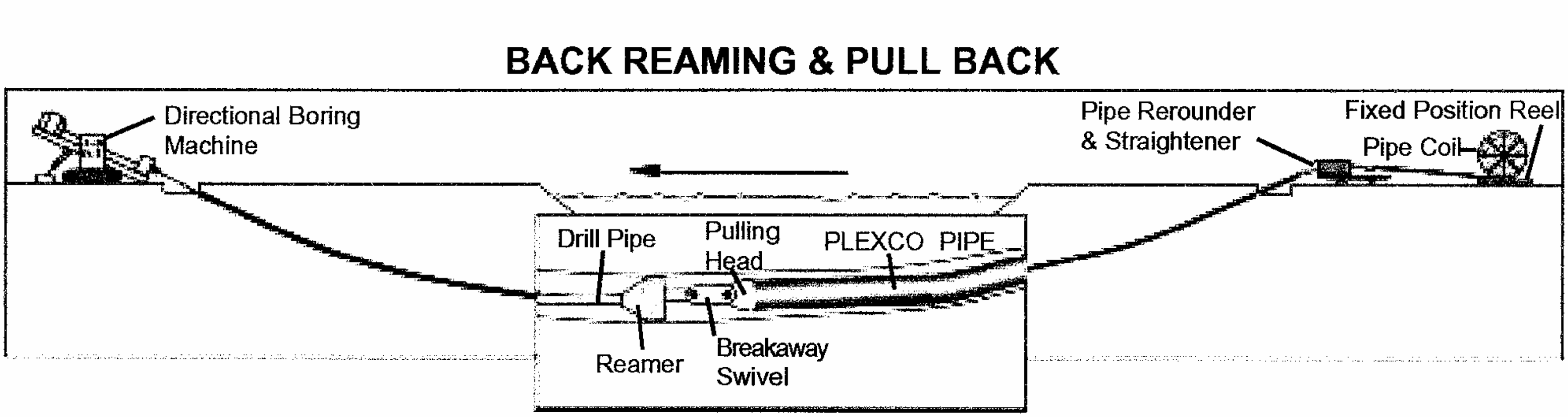
# HORIZONTAL DIRECTIONAL DRILLING (HDD)

## PILOT HOLE DRILLING




## PREREAM



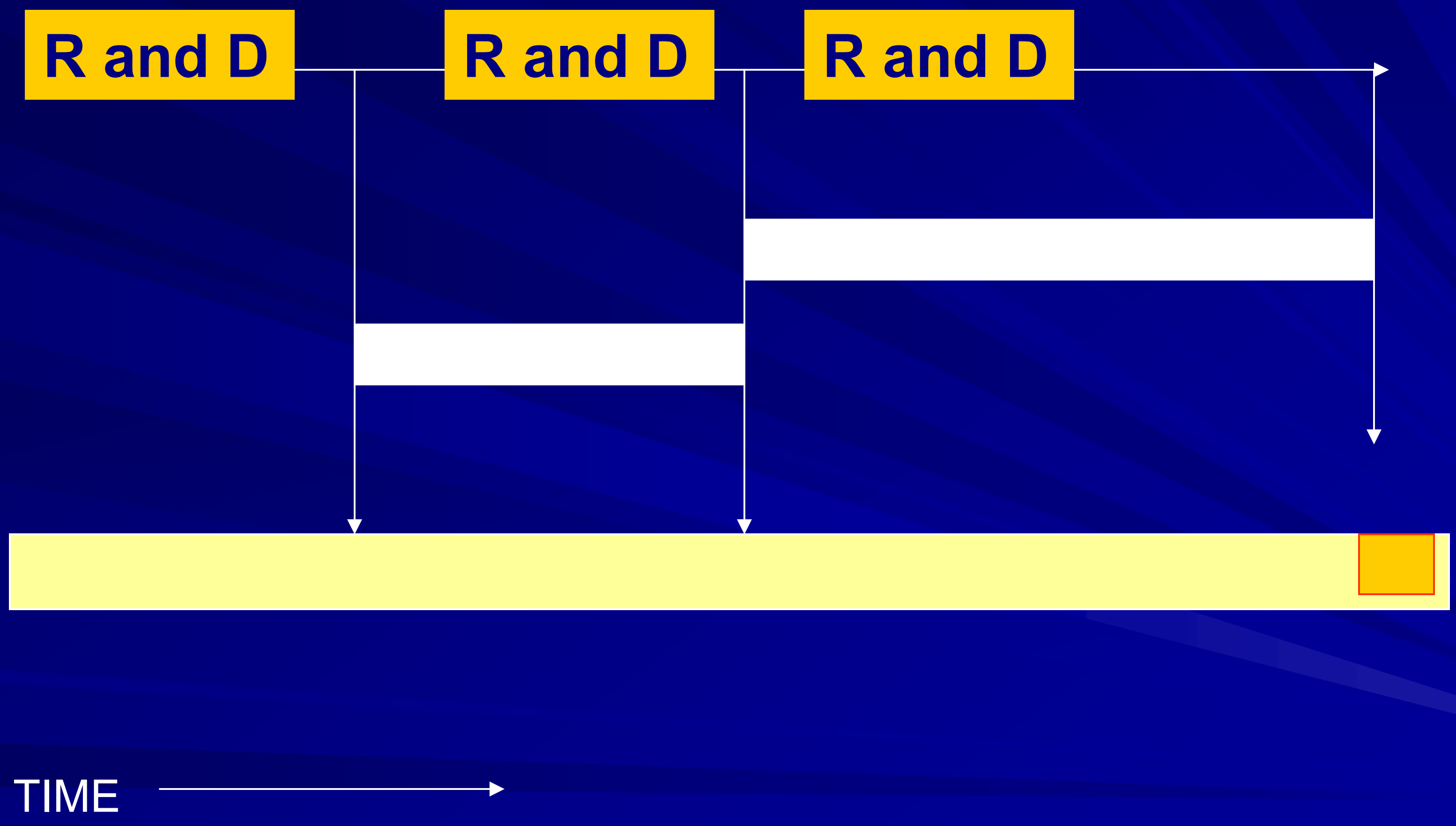



- HDD CAPABILITIES TO DATE
  - Maximum distance: 6000 ft at 24 in. dia.
  - Maximum diameter: 48 in. over distance of 3000 ft
- Excavation and Steering
  - EM signal transmitted to surface or through single hard wire line in casing: inclination and magnetic azimuth
  - Circulating fluid pumped to mud motor or jets to excavate ground. Steering controlled by small rotations of pipe to adjust attack angle of motors or cutting tool.

# 3 Ways to be more efficient/ cost effective

- 1. Increase advance rate
- 2. Reduce crew size
- 3. Reduce Risk
  - To Bidder/Construction Contractor
  - Better Contracting Practices
  - Reduce delays/ cost overruns
  - Robust tunneling equipment
  - Methods insensitive to variable ground conditions

# Development



# Order of magnitude

- Fiber optic conduit: trenching $50-100/ft
- Conduit: pipe jacking,
  directional drilling: $200/ft
- Larger: 2- to 4-ft-dia micro tunnel: $500/ft
- Optimum-sized TBM tunnel $1500/ft
- Larger TBM tunnels $3000/ft

# Supergrid Opportunities

- Long-term project
- Large capital costs for installation
- Special requirements for installing the grid: tunnel size, lengths of runs, ranges of ground conditions to be encountered.
- Trend with time: less space and more difficult access for installing utlities. Less public tolerance for disturbance
- Increasing use of tunneling and trenchless technologies rather than trenching and open excavation.
- Focus for improving tunneling technology for supergrid:
  - Contracting practices: mitigation and assignment of risk
  - Joint efforts with research groups, engineering firms, contractors, and machine manufactures to develop and demonstrate excavation and tunneling systems that will fit the requirements of the project
  - Link directional drilling, micro-tunneling and larger tunnel boring machine technologies.
  - Support demonstration projects using advanced technologies for driving tunnels.

# EPB & Slurry Shield Opportunites

- Ability to change cutters, maintain face, particularly in ground with high pressure, high permeability ground water and gas.
  - Flood doors
  - Back loading cutters
  - Robotics: New technology
  - Wear sensors on cutters and rolling disks
- Maintain circulation and minimize loss of slurry into voids, high permeability zones
- Reduce risks of large local ground losses
  - Improve EPB conditioners used to mix soil and develop pressure on the face
  - Improve monitoring of volume in and out of head.
  - Real time readout of machine functions and grout and conditioner volume and pressure, link readout to control of machine
  - Sensing of conditions ahead of shield requiring adjustment in slurry or conditioners.
  - Reduce dependence on operator's control

# Segmental lining opportunities

- Automate lining installation procedures
- Improve seals
- Improve tail grouting techniques
- Improve remedial measures for chasing down and sealing leaks.
- Improve toughness of concrete: fibers, reduce corner cracking.
- Longer segment lengths
- Install while tunnel is advanced

# Pipe jacking (micro-tunneling) opportunities

- Extend total length of runs
- Develop for larger diameters (10-15 ft)

# Hole through