DESIGN AND CONSTRUCTION OF THE HARLAN TUNNELS

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Duty Location Nashville, TN
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Project Location
The Problem

April 1977
Why In Harlan?

Cumberland River

Poor Fork

Clover Fork

Martins Fork

Flow Directions
The Recommended Plan

- Diversions
- Levees and floodwalls
- Pump stations and gravity outlets
- Non-structural
The Project Layout

Abandoned Natural Channel

Tunnels

Harlan Study Area

SPF Protection
Aerial View Along Tunnel Alignment
Feasibility of Tunnels

Typical debris load on bridge after April 1977.
Physical Model, Waterways Experiment Station - Flow Test
Modeling the Intake With Debris.
The Tunnels Relative to Human Size.
Geology of the Project

Approximate Location of Harlan

Landsat View, South of the Project

Valley and Ridge
Geologic Cross-section

Pine Mountain Overthrust Fault

Pine Mountain
Haian Tunnels
Cumberland Mountain
Typical Section Exposed on Road Cut at Highway 421.

A good location for gathering strikes and dips.
The Exploration Program

Horizontal Hole Drilling
Single Shot Camera Borehole Survey System.
Core Recovery From the Horizontal Drilling

70% recovered as 10 ft. unbroken cores.
Videotaping the Holes
Polar Plot of Discontinuities

Different symbols for different data sources such as angle holes, televiewer, or surface mapping.
Point Load Testing Apparatus
Typical Sample After Testing
Point Load Test Data For Hole CH-1

![Graph showing Point Load Test Data](image)
Other Field Testing.
Pull Break Tensile Test

Approximate Tensile Strength (PSI)

This data is based on the hydraulic pressure required to break the core after each run. It approximates the tensile strength of the rock.

Depth in Feet

- Along Beds
- Across Beds
Cross-hole Seismic Velocity Profiling
Why Do the Profiling?

Ripping can be cheaper but is it feasible?
Estimating Ripping Production Vs. Seismic Velocity of the Rock Mass
Direct Shear Test Averages
X-ray Diffraction Data

Percent Mineralogy

CH-1  CH-1  C-206  C-204  C-202  C-204  C-204  C-206

Marker Beds

% Dolomite  % Calcite  % Feldspar  % Chlorite  % Kaolinite  % Illite  % Quartz

 Hole Numbers
Unconfined Compressive Strength.
## Rock Mass Classification System Analysis

### RMR System (CSIR)

<table>
<thead>
<tr>
<th>Factor</th>
<th>High Value</th>
<th>Low Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock UCS Strength (10,557 psi - 5,412 psi)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>RQD Rating (95 - 100)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Joint Spacing (1 Ft. - 10 Ft.)</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Joint Roughness (Very Rough - Slightly Rough)</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Groundwater (Dry - Moist)</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Adjustment for Joint Orientation (Bedding)</td>
<td>-10</td>
<td>-10</td>
</tr>
<tr>
<td>Rock Mass Rating</td>
<td></td>
<td></td>
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<tr>
<td>Rock Classification</td>
<td>82</td>
<td>61</td>
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</tbody>
</table>

**Rock Mass Rating**
- **Very Good**
- **Good**
Rock Mass Classification System Analysis  
Q System (NGI)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>High Value</th>
<th>Low Value</th>
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<tbody>
<tr>
<td>1.</td>
<td>RQD</td>
<td>Range From Borings</td>
<td>100</td>
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<tr>
<td>2.</td>
<td>J_n</td>
<td>Joint # (Massive to One Joint Set)</td>
<td>2.0</td>
</tr>
<tr>
<td>3.</td>
<td>J_r</td>
<td>Joint Roughness (Smooth to undulating)</td>
<td>4.0</td>
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<tr>
<td>4.</td>
<td>J_a</td>
<td>Joint Alteration (Unaltered)</td>
<td>1.0</td>
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<tr>
<td>5.</td>
<td>J_w</td>
<td>Joint Water (Dry to Minor Inflows)</td>
<td>1.0</td>
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<tr>
<td>6.</td>
<td>SRF</td>
<td>Stress Reduction Factor (Low to Medium)</td>
<td>2.5</td>
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</tbody>
</table>

Q = RQD/J_n * J_r /J_a * J_w/ SRF

Maximum Q = 100/0.5 * 4/1 * 1/1 = 800 .............. Extremely Good Quality Rock

Minimum Q = 95/2 * 3/1 * 1/2.5 = 57 .............. Very Good Quality Rock
Boundary Element Analysis

Overstress zones
Tunneling Methods

- **Drill and blast** - most commonly used flexible. Disruptive to rock mass.

- **Tunnel boring machines** - For long tunnels most economical. Least flexible. Least disruptive to rock mass.

- **Road headers** - limited rock strength. Most flexible. Not disruptive to rock mass.
Tunnel Excavation Plan

Phase I Top Heading by Road Header.

Phase II Bench by drill and blast with wall trimming by Road Header.
Two Heavy Duty Machines

**Purat E242 (German)**
- Weight: 120 tons
- Length: 54’ 6”
- Height: 12’ 11”
- Width: 13’ 3”
- Conveyor: 50 hp
- Hydraulic Drive: 131 hp
- Cutter: 402 hp

**DOSCO MK3 (British)**
- Weight: 93 tons
- Length: 40’
- Height: 9’ 8”
- Width: 13’ 1”
- Conveyor: 48 hp
- Hydraulic Drive: 180 hp
- Cutter: 370 hp
Production Comparison

Excluding Downtime

Paurat Vs. Dosco

Average Production (Bank Cy/Day)

Dosco
Paurat

Downtime/repairs
Production Comparison

Paurat Vs. Dosco

Average Production (Bank Cy/Day)

Including Downtime

Dosco

Paurat

Top Heading Excavation
Paurat Vs. Dosco
Road Headers at Work
Blasting the Bench
Tunnel Utility Layout

- Springline
- Excavation Line
- 3 ft.
- 45°
- 2" Water Line
- 60° Ridgid Vent. Pipe
- Laser Mounting
- 4" Airline
- Main Power Cable
- Lighting Power
Ventilation System Design
Silicosis Is a Concern!

Air Requirements:

<table>
<thead>
<tr>
<th>Description</th>
<th>Requirement</th>
<th>Calculation</th>
<th>Result</th>
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</thead>
<tbody>
<tr>
<td>Diesel Engines</td>
<td>900 H.P.</td>
<td>$900 \times 100$</td>
<td>$90,000$</td>
</tr>
<tr>
<td>Personnel</td>
<td>15 Men</td>
<td>$15 \times 200$</td>
<td>$3,000$</td>
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<tr>
<td>Total Required</td>
<td></td>
<td></td>
<td>$93,000$</td>
</tr>
</tbody>
</table>

System Used = 100,000 C.F.M. → Air Velocity in top heading = 200 FPM

Fan System
Jet Air Fan Model R-4200-B w/ 200 H.P., 1,800 RPM Motor
At the Heading

60” Suction Line

Scrubber
Scrubber
Alignment With Lasers
Support of the Roof.....
Rock Bolts

10’ long 1” Ø steel bolts on 5 foot centers.
Support of the Roof....... Shotcrete.

4" minimum of steel fiber reinforced shotcrete
The Upstream Portal
The End