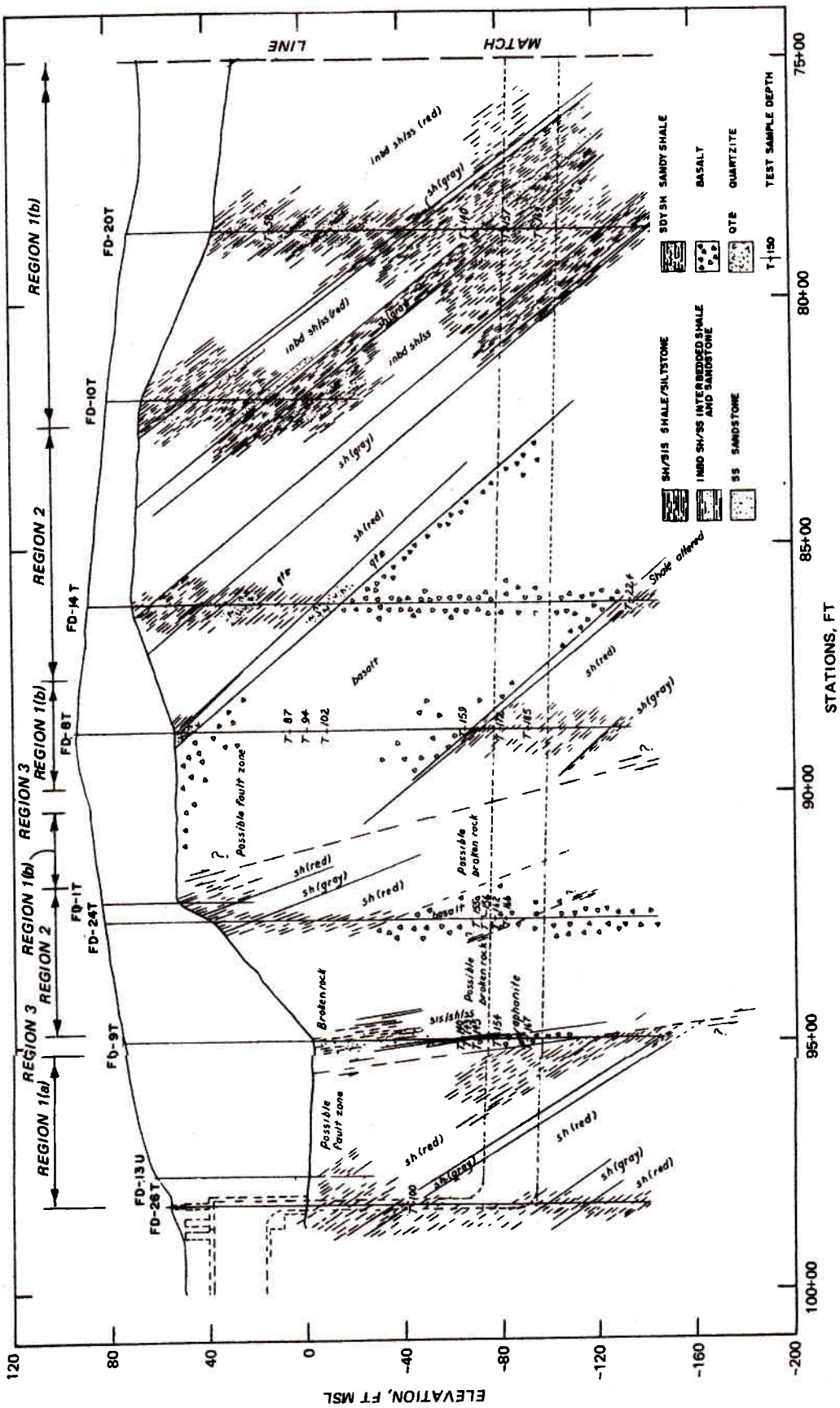

Figure 18. Geologic profile of Park River Tunnel (Sheet 1 of 4)

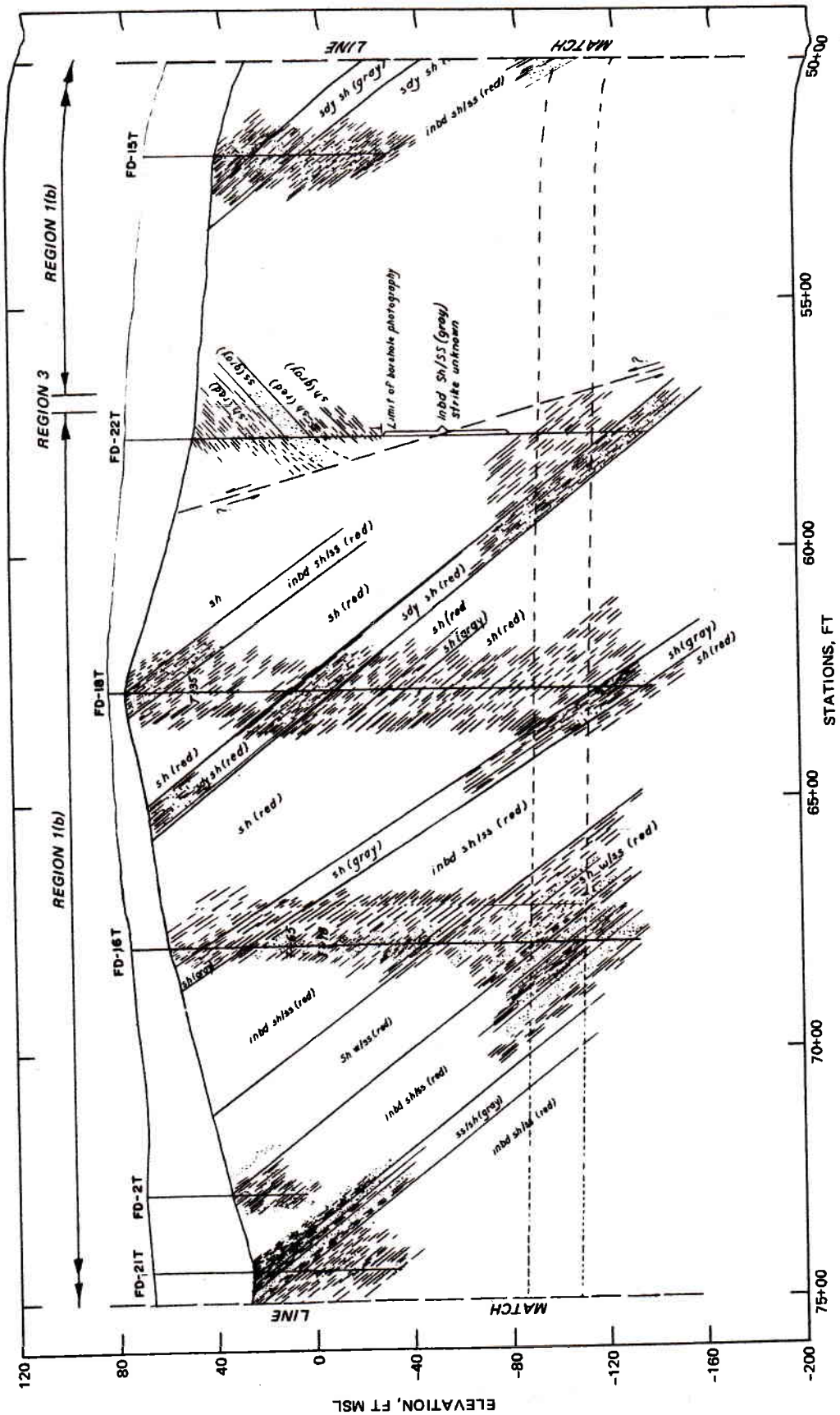

Figure 18. (Sheet 2 of 4)

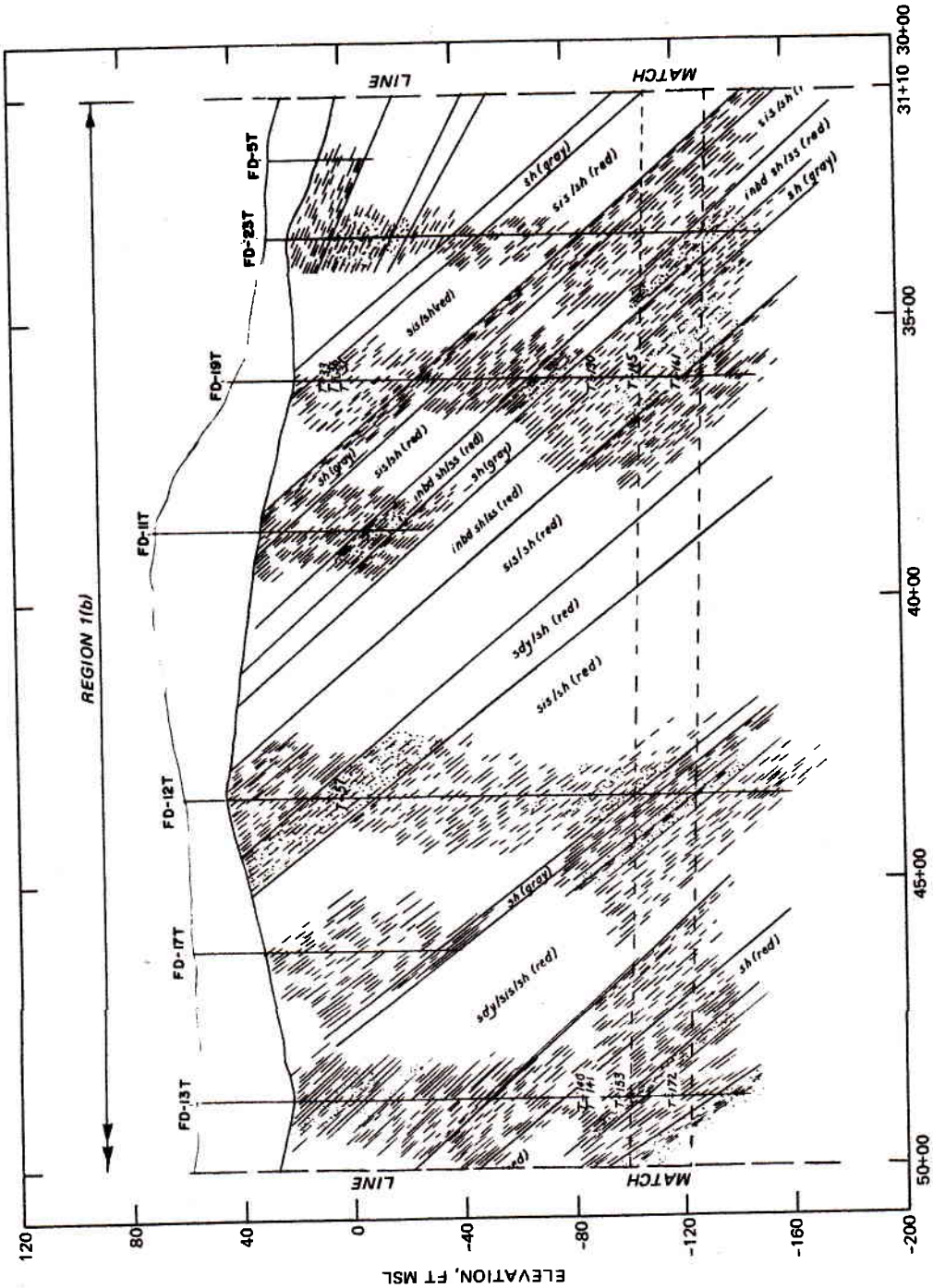

Figure 18. (Sheet 3 of 4)

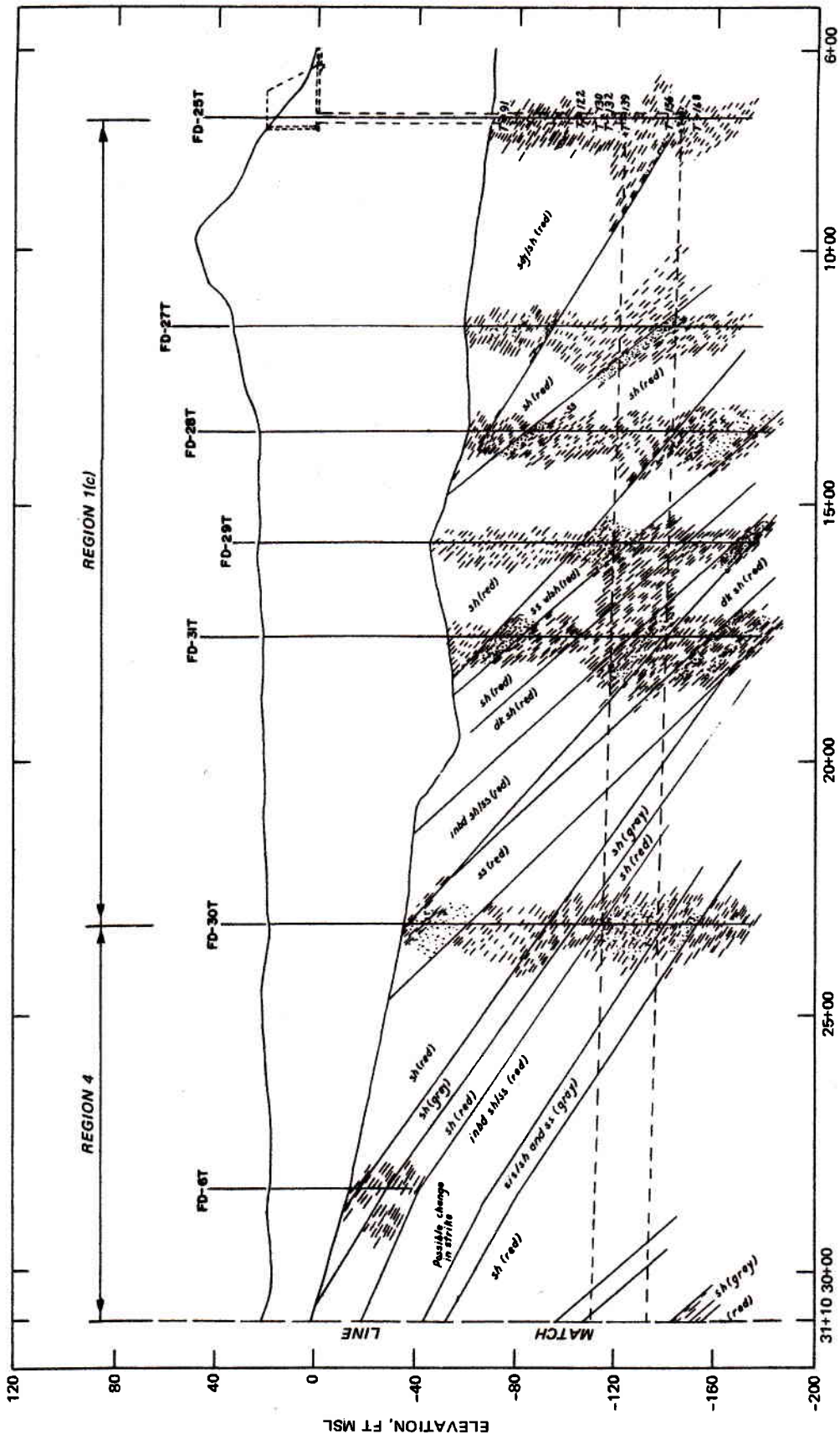

Figure 18. (Sheet 4 of 4)

Name of project: *Park River Tunnel*
Site of survey: *Hartford, Conn.*
Conducted by: *G. A. N.*
Date: *July 15, 1978*

STRUCTURAL REGION	ROCK TYPE AND ORIGIN
23+10-7+10+	*Shale with interbedded sandstone*

DRILL CORE QUALITY R.Q.D.*		WALL ROCK OF DISCONTINUITIES
Excellent quality:	90 - 100%	Unweathered
Good quality:	75 - 90%	Slightly weathered ✓
Fair quality:	50 - 75% ✓	Moderately weathered
Poor quality:	25 - 50%	Highly weathered
Very poor quality:	<25%	Completely weathered
*R.Q.D. = Rock Quality Designation		Residual soil

GROUND WATER	STRENGTH OF INTACT ROCK MATERIAL			
INFLOW per 10 m of tunnel length	litres/minute	Designation	Uniaxial compressive strength, MPa	OR Point-load strength index, MPa
or		Very high:	Over 250	>10
WATER PRESSURE	kPa	High:	100 - 250	4-10
or		Medium high:	50 - 100 ✓	2-4
GENERAL CONDITIONS (completely dry, damp, wet, dripping or flowing under low/medium or high pressure:		Moderate:	25 - 50 ✓	1-2
Dripping		Low:	5 - 25	< 1
		Very low:	1 - 5	

SPACING OF DISCONTINUITIES

		Set 1	Set 2	Set 3	Set 4
Very wide:	Over 2 m				
Wide:	0,6 - 2 m		✓		
Moderate:	200 - 600 mm	✓			
Close:	60 - 200 mm				
Very close:	<60 mm				

NOTE: These values are obtained from a joint survey and not from borehole logs.

STRIKE AND DIP ORIENTATIONS

Set 1	Strike:	*N23E* (average)	(from *N5E*	to *N35E*)	Dip: *20* (angle)	*SE* (direction)
Set 2	Strike:	*N47E*	(from *N40E*	to *N60E*)	Dip: *20*	*SE*
Set 3	Strike:		(from	to	) Dip:	
Set 4	Strike:		(from	to	) Dip:	

CONDITION OF DISCONTINUITIES

PERSISTENCE (CONTINUITY)		Set 1	Set 2	Set 3	Set 4
Very low:	<1 m				
Low:	1 - 3 m				
Medium:	3 - 10 m				
High:	10 - 20 m	✓	✓		
Very high:	> 20 m				
SEPARATION (APERTURE)					
Very tight joints:	<0,1 mm				
Tight joints:	0,1 - 0,5 mm				
Moderately open joints:	0,5 - 2,5 mm	✓	✓		
Open joints:	2,5 - 10 mm				
Very wide aperture	> 10 mm				
ROUGHNESS (state also if surfaces are stepped, undulating or planar)					
Very rough surfaces:					
Rough surfaces:		✓	✓		
Slightly rough surfaces:					
Smooth surfaces:					
Slickensided surfaces:					
FILLING (GOUGE)					
Type:					
Thickness:					
Uniaxial compressive strength, MPa					
Seepage:					

MAJOR FAULTS OR FOLDS

Several small fracture zones were found in core logs. Zones range from 100 mm to 0.3 m in thickness and occur between sta. 16+00-13+50.

Describe major faults and folds specifying their locality, nature and orientations.

GENERAL REMARKS AND ADDITIONAL DATA

Random joints present

NOTE:
(1) For definitions and methods consult ISRM document: *'Quantitative description of discontinuities in rock masses.'*
(2) The data on this form constitute the minimum required for engineering design.

erected in the tail shield of the TBM about 11 to 12 m behind the cutter face. Each of the four segments was 22.9 cm thick and about 1.8 m wide. A completed ring provided a finished inside diameter of 6.7 m. Circumferential sponge rubber O-rings were provided between rings, and neoprene pad gaskets and a hydraulic cement sealant were used between segments (Engels et al., 1981).

GUIDED DESIGN PROBLEM

Design a 50-meter long section of the tunnel based on the geological and engineering information discussed above.

The section to be designed is an extension of the tunnel due to relocation of the tunnel outlet. Positioned near the outlet, the section is 20 meters below the surface.

Perform the following tasks:

1. Classify the rock mass conditions in accordance with:
   a) Terzaghi method,
   b) RSR concept,
   c) Geomechanics Classification (RMR),
   d) Q-system.
2. Calculate the rock loads by means of each of the above four methods and for two alternatives: drill-and-blast tunnel and machine bored tunnel.
3. Determine the self-supporting span and the maximum span possible for the encountered rock mass conditions.
4. Estimate the stand-up time, rock mass deformability and the friction and cohesion of the rock mass.
5. Select the tunnel support in accordance with the four methods specified in Item 1.
6. Select the final lining.
7. Tabulate the results for Items 1 to 6 in a manner suitable for a convenient comparison of the alternatives.
8. Recommend the method of excavation and decide on the type of support.
9. Estimate the cost of the tunnel section.
10. Draw a tunnel cross-section showing the layout of support and any recommended monitoring instrumentation.

SOLUTION

Item 1: Classification of rock mass conditions

a) Terzaghi: 'Moderately blocky and seamy' (RQD = approx. 72%)

b) RSR concept:

- Rock type: soft sedimentary rock;
- Slightly faulted and folded;
- Parameter $A = 15$;
- Spacing: moderate to blocky;
- Strike approx, perpendicular to tunnel axis, dip 0–20°;
- Parameter: $B = 30$;
- Water inflow: moderate;
- Joint conditions: fair (moderately open, rough and weathered);
- For: $A + B = 45$, parameter $C = 16$;
- Therefore: RSR = 15 + 30 + 16 = 61.

c) Geomechanics Classification (RMR):

- Intact rock strength, $\sigma_c = 50$ MPa
  Rating = 4;
- Drill core quality, RQD = 55–85%; Ave. 72%
  Rating = 13;
- Spacing of discontinuities, range: 50 mm to 0.9 meters
  Rating: 10;

- Condition of discontinuities: separation 0.8 mm to 1.1 mm, slightly weathered, rough surfaces
  Rating: 25;
- Groundwater: dripping water, low pressure, flow 25–125 liters/min.
  Rating 4;
- Basic RMR: 4 + 13 + 10 + 25 + 4 = 56 without adjustment for orientation of discontinuities;
- Discontinuity orientation: strike perpendicular to tunnel axis, dip 20°;
  Fair orientation. Adjustment: –5,
  Adjusted RMR = 56–5 = 51;
- RMR = 51, represents Class III: Fair rock mass.

d) Q-System:

- RQD = 72% (average);
- $J_n = 6$, two joint sets and random;
- $J_r = 1.5$, rough, planar joints;
- $J_a = 1.0$, unaltered joint walls, surface staining only;
  $J_w = 0.5$, possible large water inflow;
- SRF = 1.0, medium stress, $\sigma_c/\sigma_1 = 50/0.91 = 55$.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} = \frac{72}{6} \times \frac{1.5}{1} \times \frac{0.5}{1} = 9.0$$

Fair rock mass

Summary:

Classification	Result	
Terzaghi	Moderately blocky & seamy	
RSR	61	
RMR	51	Fair rock mass
Q	9.0	Fair rock mass

Item 2: Rock loads
Drill-and-blast diameter: 7.4 m + 0.6 m overbreak = 8.0 m
Machine-bored diameter: 7.4 m
Shale density: 2660 kg/m³ (166 lb/ft³)

Method	Drill-and-blast	TBM
Terzaghi	$h_p = 0.35C = 0.7B = 0.7 \times 8.0 = 5.6$ m Rock load $P = \gamma h_p = 0.146$ MPa (1.52 t/ft²)	$h_p = 0.45B = 3.3$ m $P = 0.09$ MPa (0.9 t/ft²)
RSR = 61	From Fig. 6.3, $P = 0.067$ MPa (1.4 kip/ft²)	TBM adjustment, Fig. 6.2 RSR = 69.5, $P = 0.034$ MPa (0.7 kip/ft²)
RMR = 51	$h_p = \frac{100 - 51}{100} B = 3.92$ m $P = \gamma h_i = 0.102$ MPa	TBM adjustment via conversion to RSR (eqn. 6.12) and Fig. 6.2 RMR = 74, $P = 0.049$ MPa
Q = 9.0	$P = \frac{2.0}{J_r} Q^{-1/3} = \frac{2.0}{1.5}(9)^{-1/3} = 0.64$ kg/cm² $= 0.0628$ MPa or $P = \frac{2J_n^{1/2}}{3J_r} Q^{-1/3} = \frac{2\sqrt{6}}{3\,1.5}(9)^{-1/3}$ $= 0.52$ kg/cm² $= 0.0513$ MPa	TBM adjustment via conversion to RSR (eqn. 6.13) and Fig. 6.2. Q = 54 $P = 0.0321$ MPa

Summary of rock-loads in kPa (1 MPa = 1000 kPa)

Method	Drill-and-blast	TBM
Terzaghi	146	90
RSR	67	34
RMR	102	49
Q	63	32

Item 3 : Self supporting span and maximum span : by RMR and Q system
Fig. 6.7: Span vs stand-up time

	RMR = 51	Q = 9 (ESR = 1.6)
Self supporting span	2.4 m	8 m
Maximum span	10.5 m	80 m [$D = 2(1.6 \times 9)^{0.4}$]

Item 4 : Stand-up time, deformability and c, ϕ values
– RMR = 51 and Span = 8 m
Stand-up time: approximately 100 hours or 4–5 days
Deformability. RMR = 56 (no adjustment for joint orientations)
$E = 2$ RMR – 100 = 12 GPa (1.74×10^6 psi)
$c = 192$ kPa
$\phi = 39°$ [Table 6.9].

Item 5 : Support recommendations

Terzaghi	Drill and blast – light to medium steel sets spaced 1.5 m. Concrete lining
RSR	Drill and blast – 6H25 ribs on 2 m centers plus final lining
RMR	Drill and blast – systematic bolts 3.5 m long – spaced 1.5 m, shotcrete 50 to 100 mm in roof and 30 mm on walls, were mesh in crown
Q system	Drill and blast – 3 m long rockbolts spaced 1.5 m and 50 mm thick shotcrete

Item 6: Final lining
100 mm thick fiber-reinforced shotcrete. See item 8.

Item 7 : Tabulation of results from Items 1–6

Item	Terzaghi	RSR	RMR	Q
Shale quality	Moderately blocky and seamy	61	51	9.0
Rock load height	5.6 m	N/A	3.9 m	N/A
Rock load	146 kPa	67 kPa	102 kPa	63 kPa
Stand-up time	N/A	N/A	4–5 days	N/A
Support	Ribs at 1.5 m Concrete lining	Ribs at 2 m Final lining	3.5 m bolts at 1.5 m, shotcrete 50 to 100 mm, wire mesh	3 m bolts at 1.5 m, shotcrete 50 mm thick

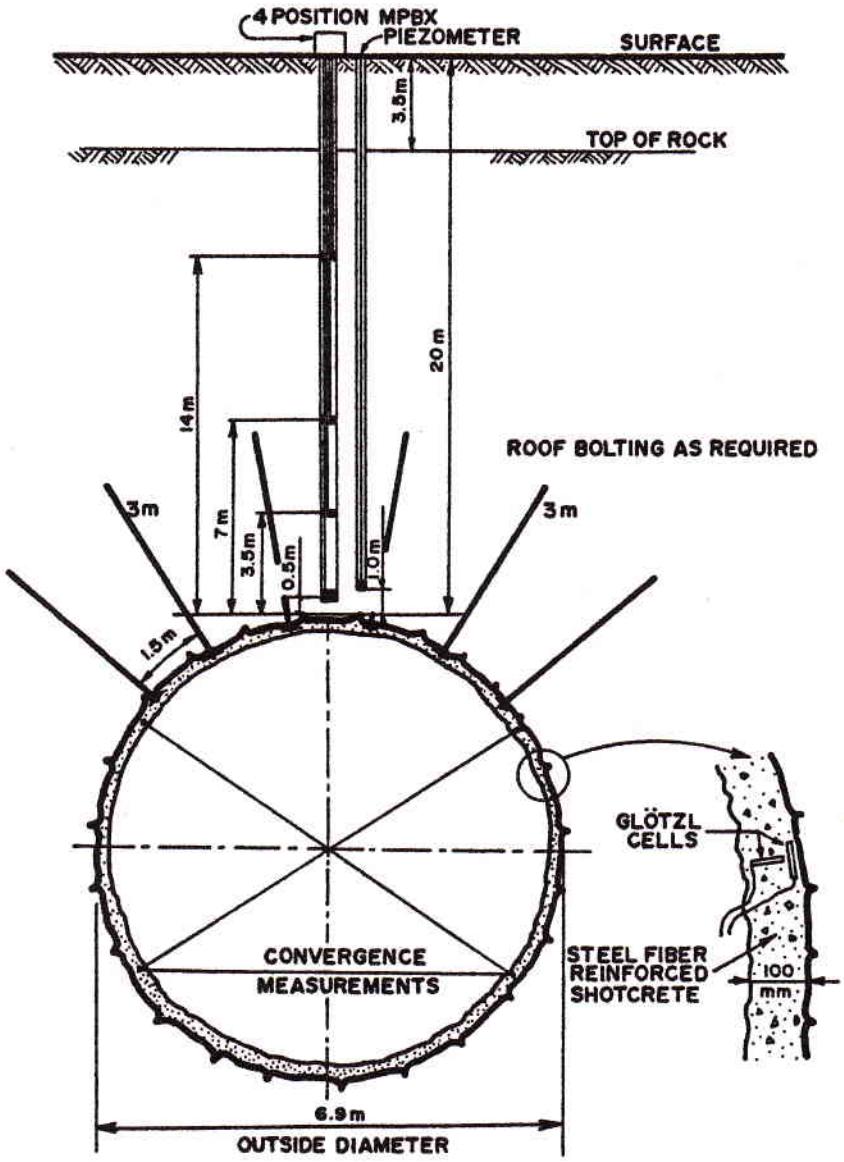

Figure 10.3. Tunnel support and instrumentation.