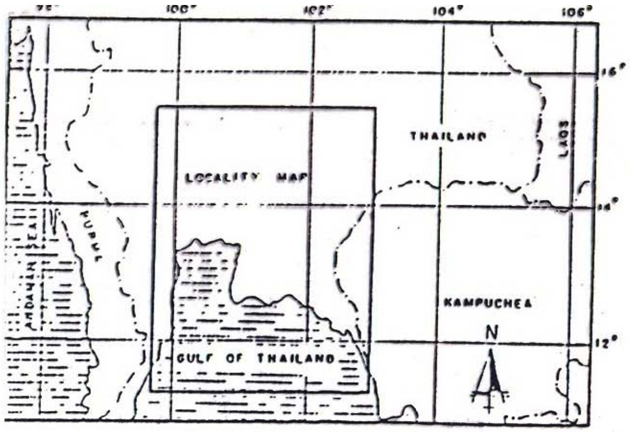
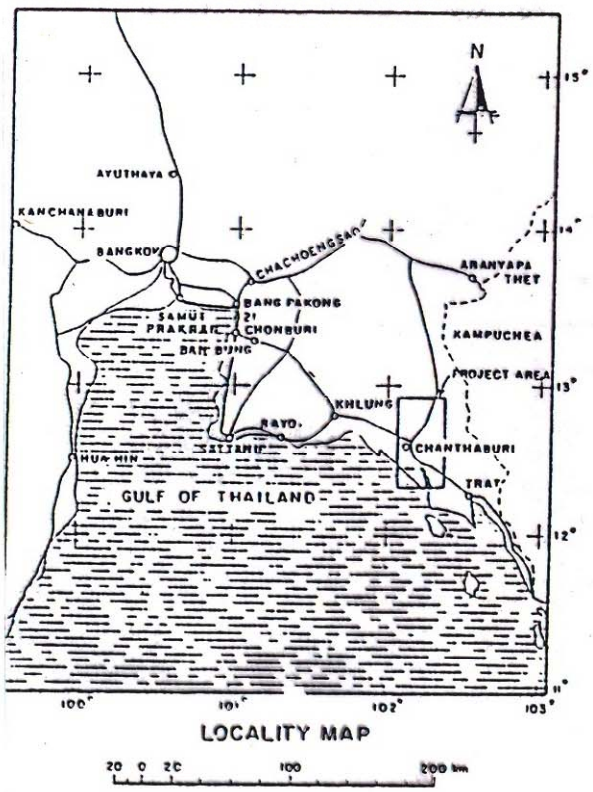
A Comparative study of Support for Power Tunnel

- Hua Saphan Hin Hydroelectric Project Location: Eastern Sea board of Thailand –near Thai-Kampuchean Border
- Intake Channel 1 km long, Main Dam 209 m above MSL, Power tunnel – 732 m long 3.2 m wide horse shaped section, feeds6.1 MW power generation units 100m below with 13.2 cu m/sec
- Thicket overburden 90 m, Meta-sedimentary rock excavated by drill and blast method.

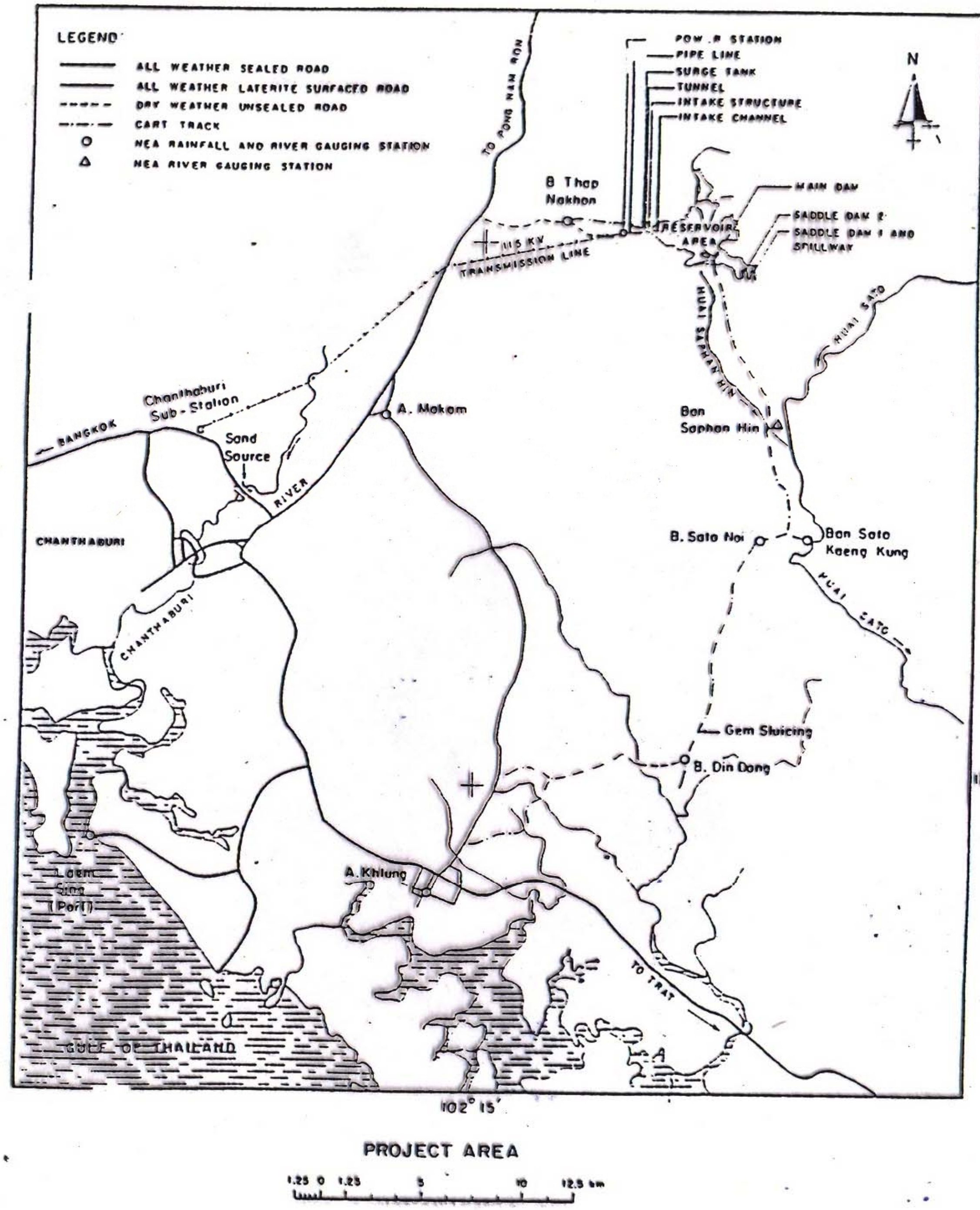
- Empirical approaches – Rock Structure Rating, Geomechanical Classification (RMR) and Barton’s Rock Mass Rating, Q
- Analytical Approach – Rock Structure Interaction Analysis, Micro- Computer program developed.



GENERAL LOCATION MAP



LOCALITY MAP



PROJECT AREA

Fig.1.1 Location and Locality Map of the Project Area

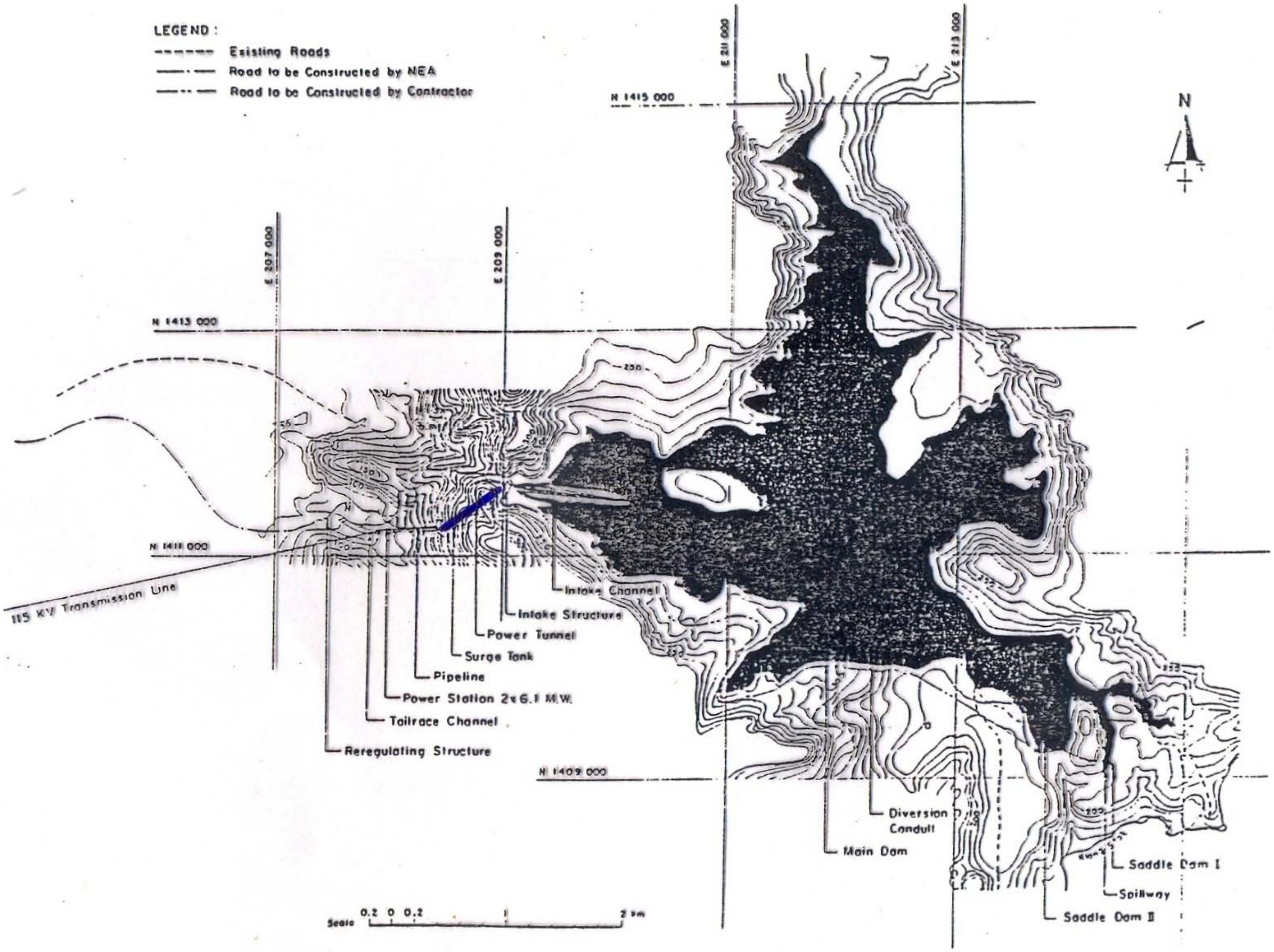


Fig. 2.1 Project Arrangement of the Huai Saphan Hin Hydroelectric Project

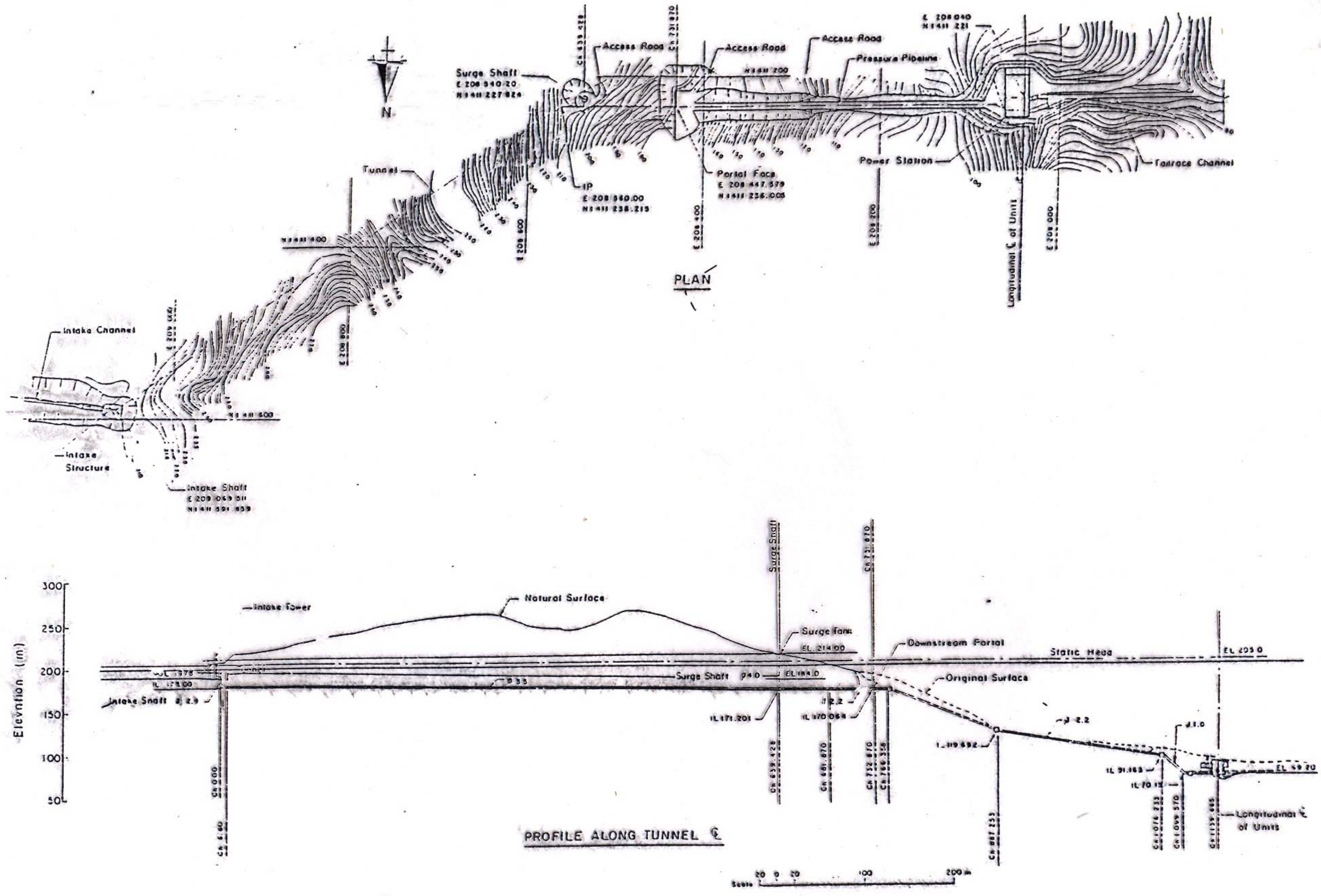


Fig. 2.2 Plan and Section of the Power Tunnel

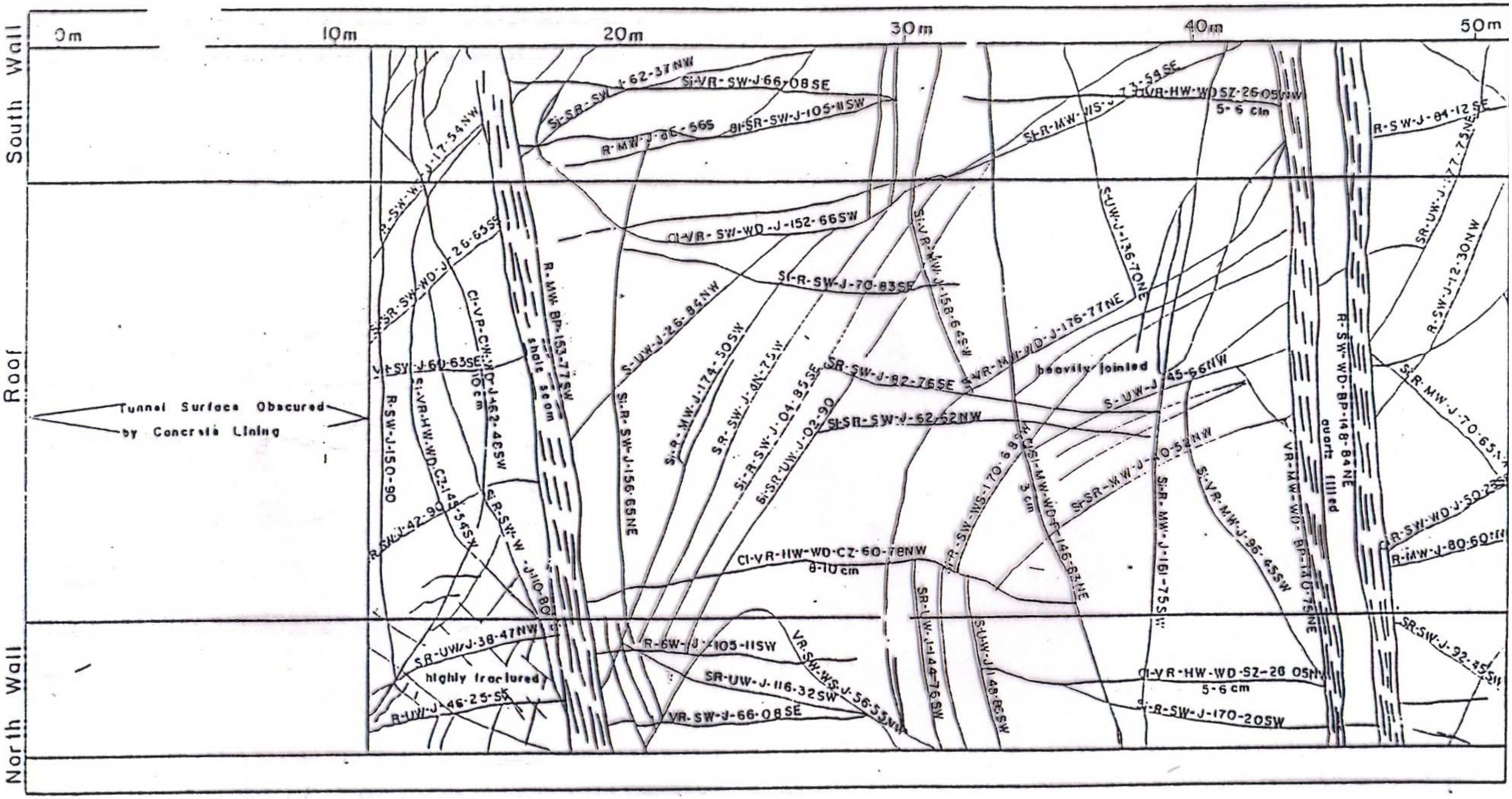


Fig. 3.6a Engineering Geologic Map of Power Tunnel, Chainage 0 m to 50 m

Table 3.1 Strike and Dip Orientations of the Joint Sets

Joint Set No.	Average Strike	Panges	Dip and Direction
1	14°	from 0° to 30°	64° S
2	52°	from 40° to 65°	54° S
3	126°	from 115° to 150°	68° N
4	161°	from 150° to 180°	65° S

Table 4.1 Features Along the Power Tunnel

Tunnel Section	Governing Joint Sets	RQD	In-situ Stress	Water Seepage
(1) Ch.11.2-150m	Set 1, Set 3 and Set 4	96-70	1.96 MPa	Heavy Inflow
(2) Ch. 150-220m	Set 2	96-70	2.12 MPa	Dripping
(3) Ch.220-320m	Set 3 and Set 4	95-32	2.27 MPa	Dripping
(4) Ch.320-550m	Set 1 and Set 3	99-76	2.42 MPa	Dripping
(5) Ch.550-732.8m	Set 1, Set 3 and Set 4	98-77	1.76 MPa	Dry

Table 4.7 Computation of Deformation Modulus

Method	Parameters Used	Modulus Em
RQD vs. Em Coon & Merrit (1970)	Max. RQD = 99% Ave. RQD = 87%	69 GPa 34.5 GPa
Joint Frequency(n) vs. Em Singh (1970)	Min. n = 5.8 Ave. n = 1.6	68 GPa 29.76 GPa
RMR vs. Em Bieniawski (1983)	Max. RMR = 87 Ave. RMR = 58	74 GPa 16 GPa
RMR vs. Em Serafim & Pereira (1983)	Max. RMR = 87 Ave. RMR = 58	19.25 GPa 12 GPa
RMR vs. Em Chapple & Maurice (1980)	Max. RMR = 87 Ave. RMR = 58	10.6[illegible] GPa 5.38 [illegible]

Table 4.8 Estimated Cost of Supports Recommended by RSR Concept

(a) Alternative 1 (Steel Set)

Section	No. of Ribs	Quantity (tons)	Quantity (tons)	Unit Price (Baht/ton)	Sub-total (Baht)
(1)	117	19.28	0.129	25,000	481,880
(2)	76	12.52	0.179	25,000	313,016
(3)	12[illegible]	20.59	0.206	25,000	514,829
(4)	165	27.18	0.118	25,000	679,575
(5)	109	17.96	0.980	25,000	448,931
Steel laggings and spreaders			58.52	27,500	1,609,233
Wooden Blocks			12.11	12,000	145,200
				Total Cost	B 4,192,664

(b) Alternative 2 (Rock bolts and Shotcrete)

Support Items	Quantity per Section (1)	(2)	(3)	(4)	(5)	Unit Price (Baht)	Sub-total (Baht)
Rock Bolts	2478m	1593m	2450m	3612m	2205m	240/m	2,961,120
Shot-crete	68.80	38.08	59.50	99.71	73.06	4000/cu.m	1,356,766
Liner Plate	2124kg	1365kg	2100kg	3096kg	1[illegible]90kg	38/kg	401,850
						Total Cost	B 2,719,736

Table 4.9 Estimated Cost of Supports Recommended by RMR Method

Support Items	Quantity per Secti n (1)	(2)	(3)	(4)	(5)	Unit Price (Baht)	Sub-total (Baht)
Rock Bolts	3200m	1504m	2144m	2760m	2208m	320/m	3,781,120
Shot-crete	27.50	59.50	85.00	83.95	66.75	4000/cu.m	1,690,790
Liner Plate	2400kg	1128kg	1608kg	2070kg	1656kg	38/kg	336,756
Wire Mesh	3825kg	1785kg	2550kg	3795kg	3017kg	24/kg	359,336
						Total Cost	B 5,168,002

Table 4.10 Estimated Cost of Supports Recommended by Q System

Support Items	Quantity per Section (1)	(2)	(3)	(4)	(5)	Unit Price (Baht)	Sub-total (Baht)
Rock Bolts (a)utg	4200m	-	-	-	-	320/m	1,344,000
(b) tg	-	-	2800m	-	-	350/m	980,000
Shot-crete	63.75	29.75	42.50	97.75	77.72	4000/cu.m	1,245,879
Liner Plate	3600kg	-	2400kg	-	-	38/kg	228,000
Wire Mesh	3188kg	-	2125kg	-	-	24/kg	127,512
						Total Cost	B 3,925,391

Note: utg = untensioned grouted bolts
tg = te sioned gro ited bolts

Table 4.11 Estimated Cost of Actual Supports Used

Suppor. It.ms	Quantity	Unit Price	Sub-total
Steel ribs	14.585 tons	25,000/ton	364,625
Steel laggings	10.442 tons	27,500/ton	287,155
Timber laggings	6.692 tons	8,750/ton	58,555
Invert struts	3.344 tons	25,000/ton	83,600
Roc. bolts	412.3 m	240/m	98,952
Liner plates	354.90 kg	38/kg	13,486
Wire mesh	119.51 kg	24/kg	2,868
Concrete	4711 cu.m	3000/cu.m	14,133,000
		Total Cost	B 15,042,241

Table 1 Features Along the Power Tunnel

Tunnel Section	Governing Joint Sets	RQD	In-situ Stress	Water Seepage
(1) Ch.11.2-150 m	Set 1, Set 3 and Set 4	96-70	1.96 MPa	Heavy Inflow
(2) Ch.150-220 m	Set 2	96-70	2.12 MPa	Dripping
(3) Ch.220-320 m	Set 3 and Set 4	95-32	2.27 MPa	Dripping
(4) Ch.320-550 m	Set 1 and Set 3	99-76	2.42 MPa	Dripping
(5) Ch.550-732.8m	Set 1, Set 3 and Set 4	98-77	1.76 MPa	Dry

Table 2 Ratings and Supports Recommended by RSR Method

Section	Condition	RSR	Support		
			Shotcrete	Bolts	Steel Ribs
1	Best	81	2.48	-	-
	Worst	46	5.31	1.28	1.29
	Average	64	3.59	2.07	3.38
2	Best	76	2.77	4.41	15.25
	Worst	38	6.36	1.09	0.93
	Average	57	4.18	1.66	2.18
3	Best	70	3.16	-	-
	Worst	34	6.99	1.01	0.80
	Average	52	4.65	1.46	1.69
4	Best	88	2.12	-	-
	Worst	48	5.08	1.34	1.69
	Average	67	3.37	2.15	3.64
5	Best	80	2.54	-	-
	Worst	52	4.65	1.46	1.69
	Average	65	3.52	2.15	3.64

Table 6 Recommended Supports Based on NGI (Q) System

Section	Condition	Ground Class	Support Type	
			Shotcrete	Block Bolts
(1)	Best Worst Average	Good Very poor Poor	None t=50 mm + (wmr) t=20=30mm	Spot bolting (utg) s=1m (utg) None
(2)	Best Worst Average	Very good Poor Fair	None t=25-50mm None	Spot bolting (utg) None s=1-1.5m (utg)
(3)	Best Worst Average	Poor Ext. poor Very good	t=25-50mm+(wmr) t=25-50mm+(wmr) t=50mm + (wmr)	s=1m (utg) s=1m (tg) s=1m (tg)
(4)	Best Worst Average	Good Very poor Fair	None t=25-50mm None	Spot bolting (utg) None s=1-1.5m (utg)
(5)	Best Worst Average	Good Poor Fair	None t=25-50mm 6=20-30mm	Spot bolting (utg) None None

Note:
t = thickness of shotcrete
s = spacing of bolts
(utg) = untensioned grouted bolts
(tg) = tensioned grouted bolts
(wmr) = wiremesh reinforced
(clm) = chainlink mesh

Table 5 Rock Mass Classification According to NGI (Q) System

Section	Condition	Parameters							Support Category
		RQD	Jn	Jr	Ja	Jw	SRF	Q	
(1)	Best Worst Average	96 70 83	9 15 10.5	3 2 2.5	0.75 3 1.8	1 0.5 0.75	2.5 2.5 2.5	17.07 0.62 3.29	13 25 17
(2)	Best Worst Average	96 70 83	2 6 5	3 2 2.5	1 3 2	1 0.66 0.85	2.5 2.5 2.5	57.60 2.05 8.82	9 21 17
(3)	Best Worst Average	95 32 64	4 6 5	2 1 1.5	2 6 4	1 0.66 0.85	10 10 10	2.38 0.06 0.41	22 33 25
(4)	Best Worst Average	99 77 88	4 9 6.5	3 2 2.5	0.75 3 1.8	1 0.66 1	2.5 2.5 2.5	39.60 1.51 6.39	13 21 17
(5)	Best Worst Average	98 77 88	9 12 10.5	3 1.5 2.3	0.75 3 1.8	1 1 1	2.5 2.5 2.5	17.42 1.28 4.28	13 21 17

Table 4 Rock Mass Class and Recommended Supports Based on RMR ,ethod

Table 4 Rock Mass Class and Recommended Supports Based on RMR Method

Section	Condition	RMR	Rock Mass Class	Support Type	
				Shotcrete	Rock Bolts
(1)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	39	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spac-ed 1-1.5m in crown and walls with wiremesh
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wire-mesh
(2)	Best	70	II	50 mm in crown where required	loca-ly bolts in crown 3m long, spaced 2.5m with occasional wire-mesh
	Worst	33	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spac-ed 1-1.5m in crown and walls with wiremesh
	Average	61	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with mesh in crown
(3)	Best	70	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wire-mesh
	Worst	33	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spac-ed 1-1.5m in crown and walls with wiremesh
	Average	61	III	50-100mm in crown required	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
(4)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	44	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wire-mesh
(5)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	44	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wire-mesh

Table 4 Rock Mass Class and Recommended Supports Based on RMR ,ethod

Table 4 Rock Mass Class and Recommended Supports Based on RMR Method

Section	Condition	RMR	Rock Mass Class	Support Type	
				Shotcrete	Rock Bolts
(1)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	39	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wiremesh
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wiremesh
(2)	Best	70	II	50 mm in crown where required	loca-ly bolts in crown 3m long, spaced 2.5m with occasional wiremesh
	Worst	33	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wiremesh
	Average	61	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with mesh in crown
(3)	Best	70	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wiremesh
	Worst	33	IV	100-150mm in crown and 100mm in sides	systematic bolts 4-5m long, spaced 1-1.5m in crown and walls with wiremesh
	Average	61	III	50-100mm in crown required	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
(4)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	44	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wiremesh
(5)	Best	82	I	Generally no support	required except for occasional bolting
	Worst	44	III	50-100mm in crown, 30mm in sides	systematic bolts 4m long, spaced 1.5-2m in crown and walls with wiremesh in crown
	Average	61	II	50mm in crown where required	locally bolts in crown 3m long, spaced 2.5m with occasional wiremesh

Table 3 Rock Mass Ratings

Section	RMR ratings for conditions		
	Best	Worst	Average
1	82	39	61
2	70	33	52
3	64	29	52
4	87	49	67
5	82	41	63

Table 7 Cost Estimate for Supports

Sr No	Type of Support Cost	Estimated Total Cost
1.	Actual Support	15,042,241
2.	Support recommended by RSR Method (Steel Sets)	4,192,664
3.	Support recommended by RSR Method (Rock Bolts & Shot-crete)	4,719,736
4.	Support recommended by RMR Method	5,168,002
5.	Support recommended by Q system	3,925,391

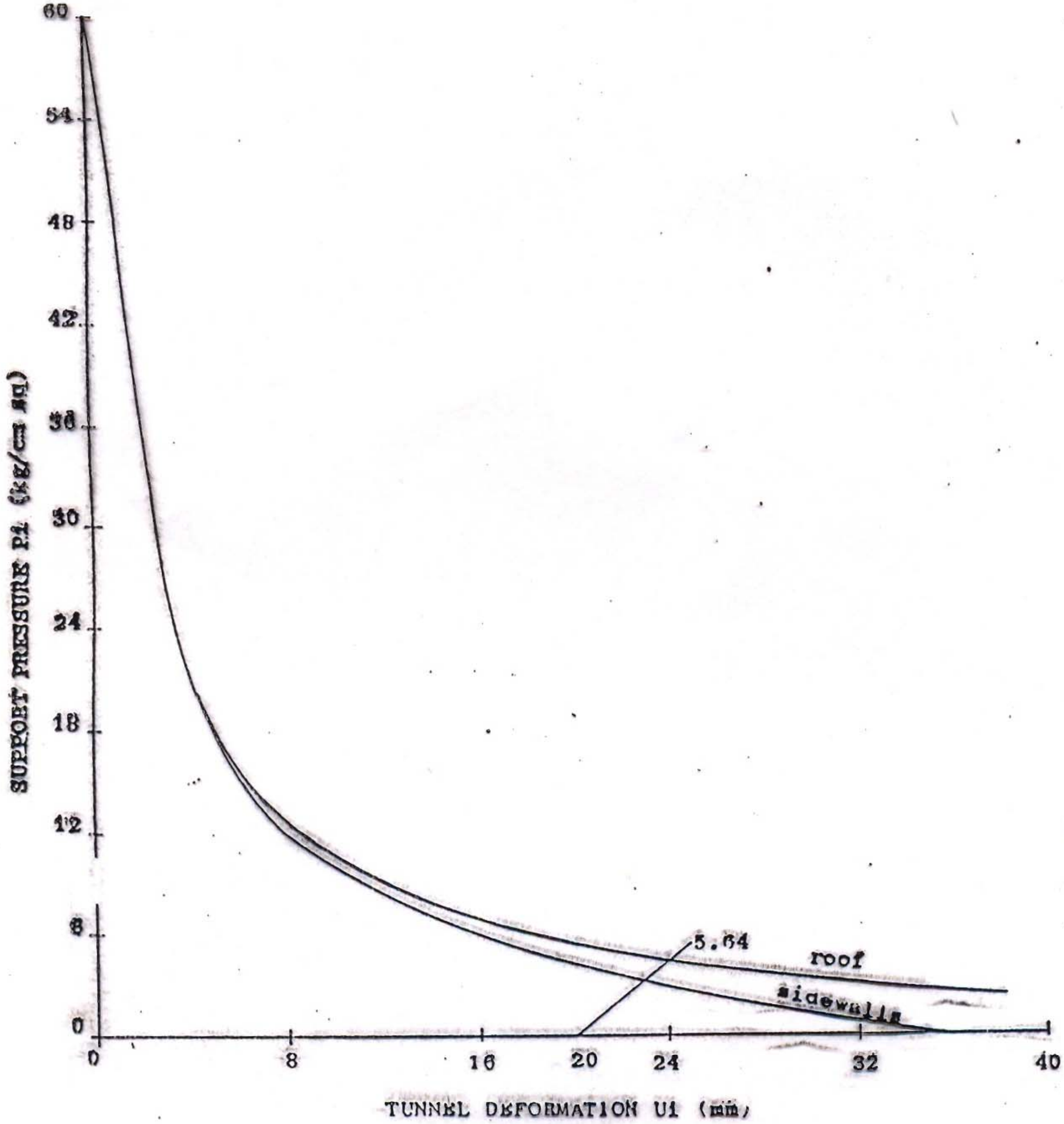


Fig.4.? Rock-Support Interaction Analysis of Rock Class III

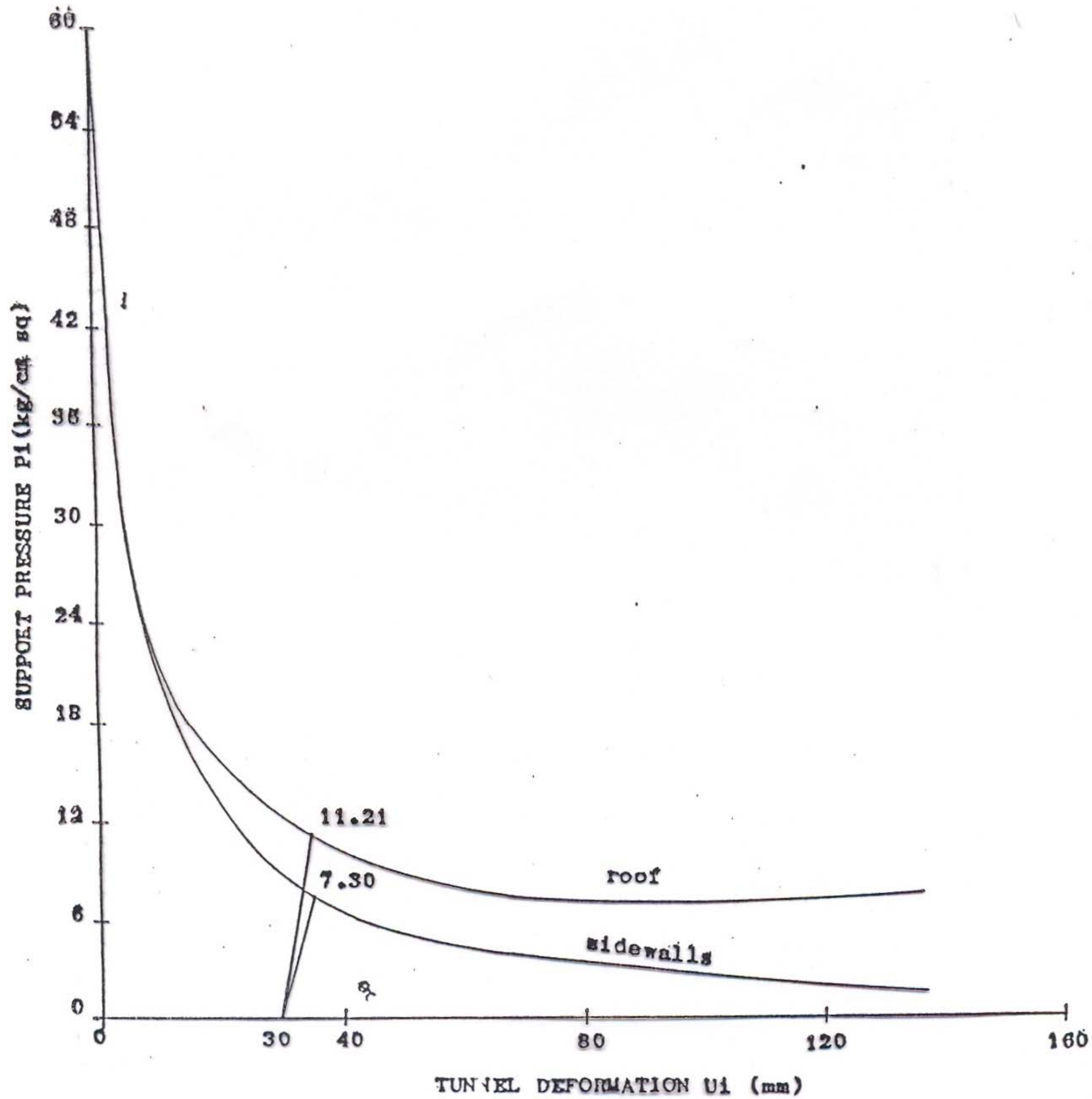


Fig.4.2 Required and Available Support Curves for Rock Support Interaction Analysis of Rock Class IV

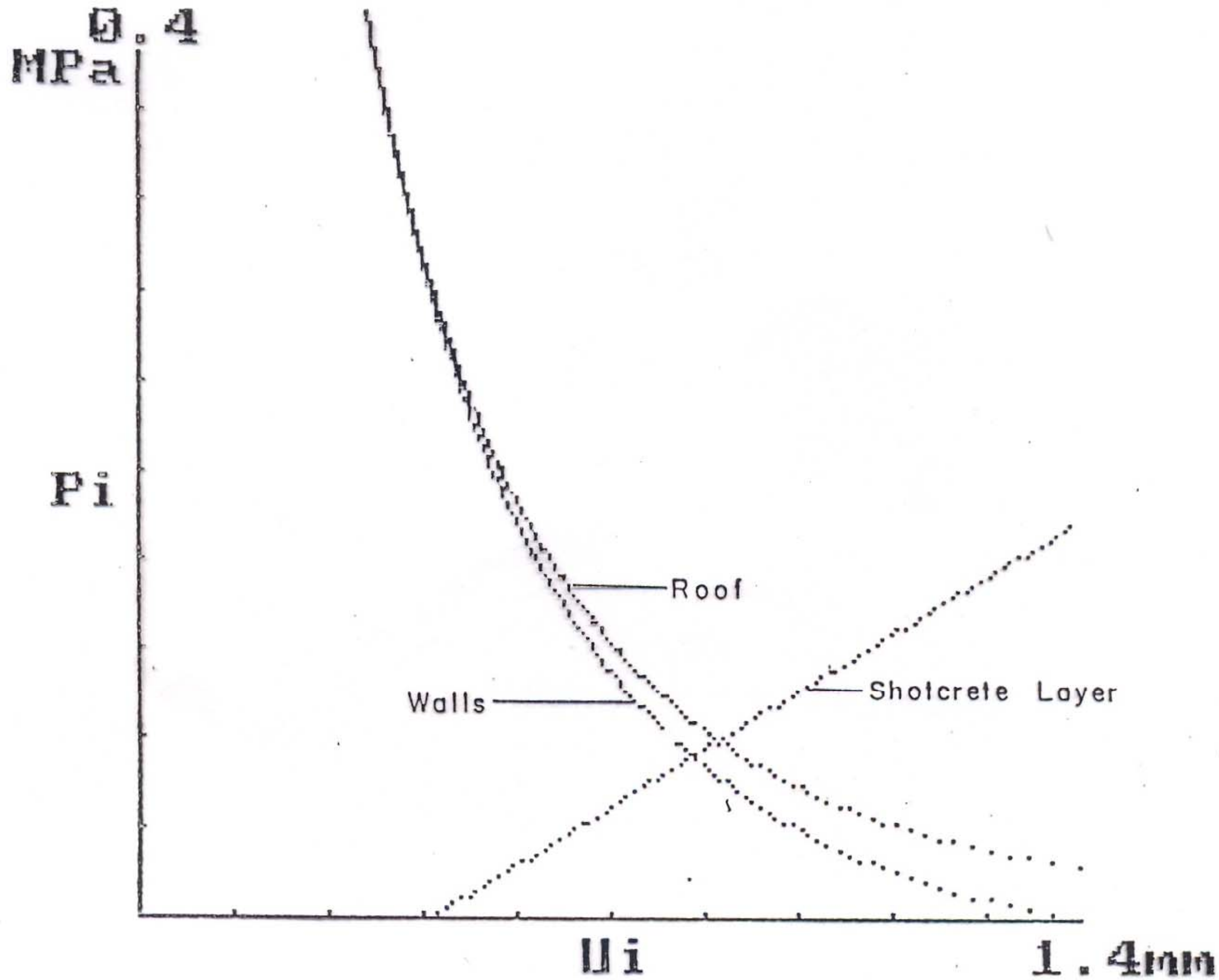


Fig.4.10 Computer Drawn Characteristic Curves for Tunnel Section (4), Using Shotcrete Layer 25 mm Thick

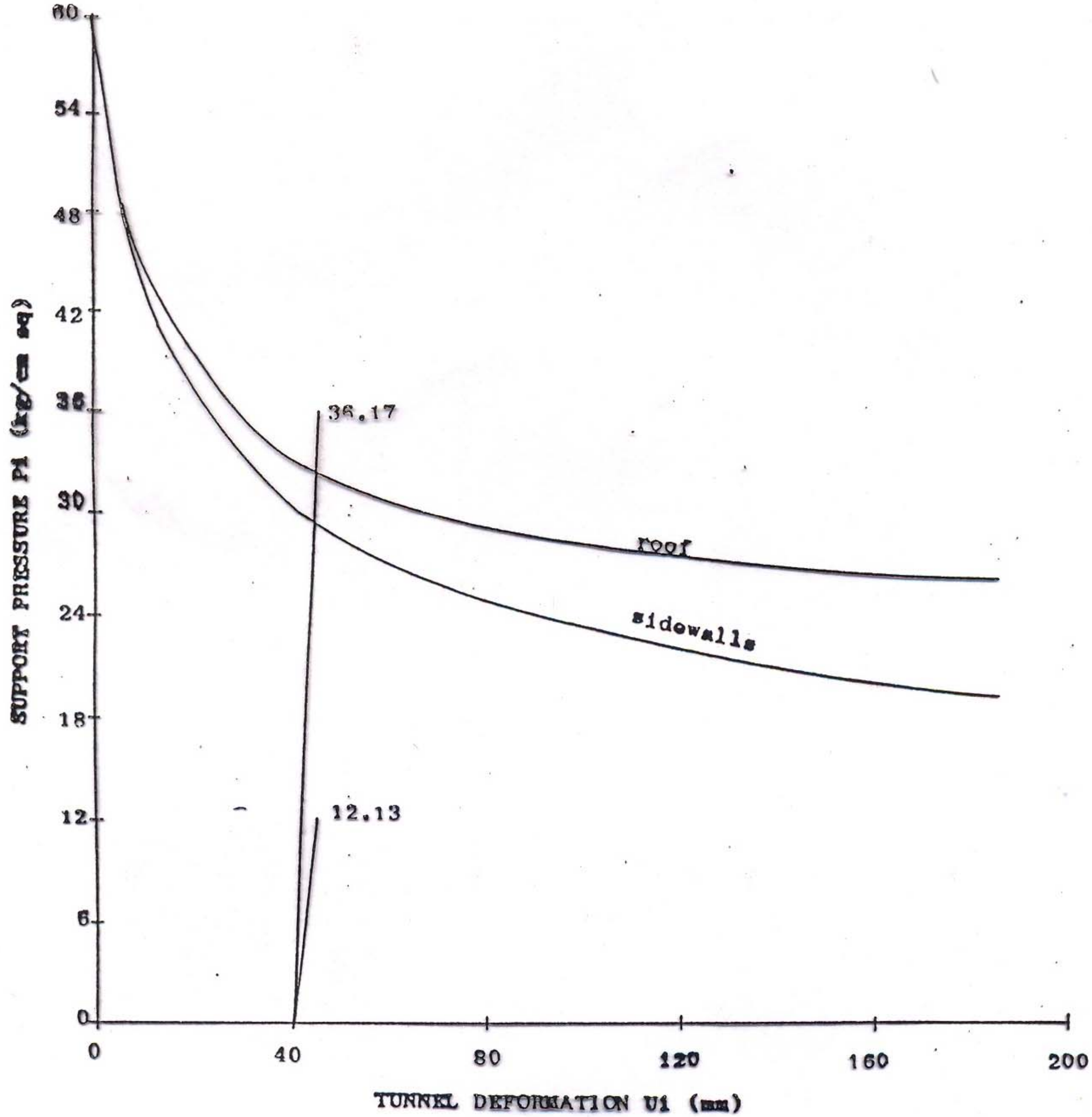
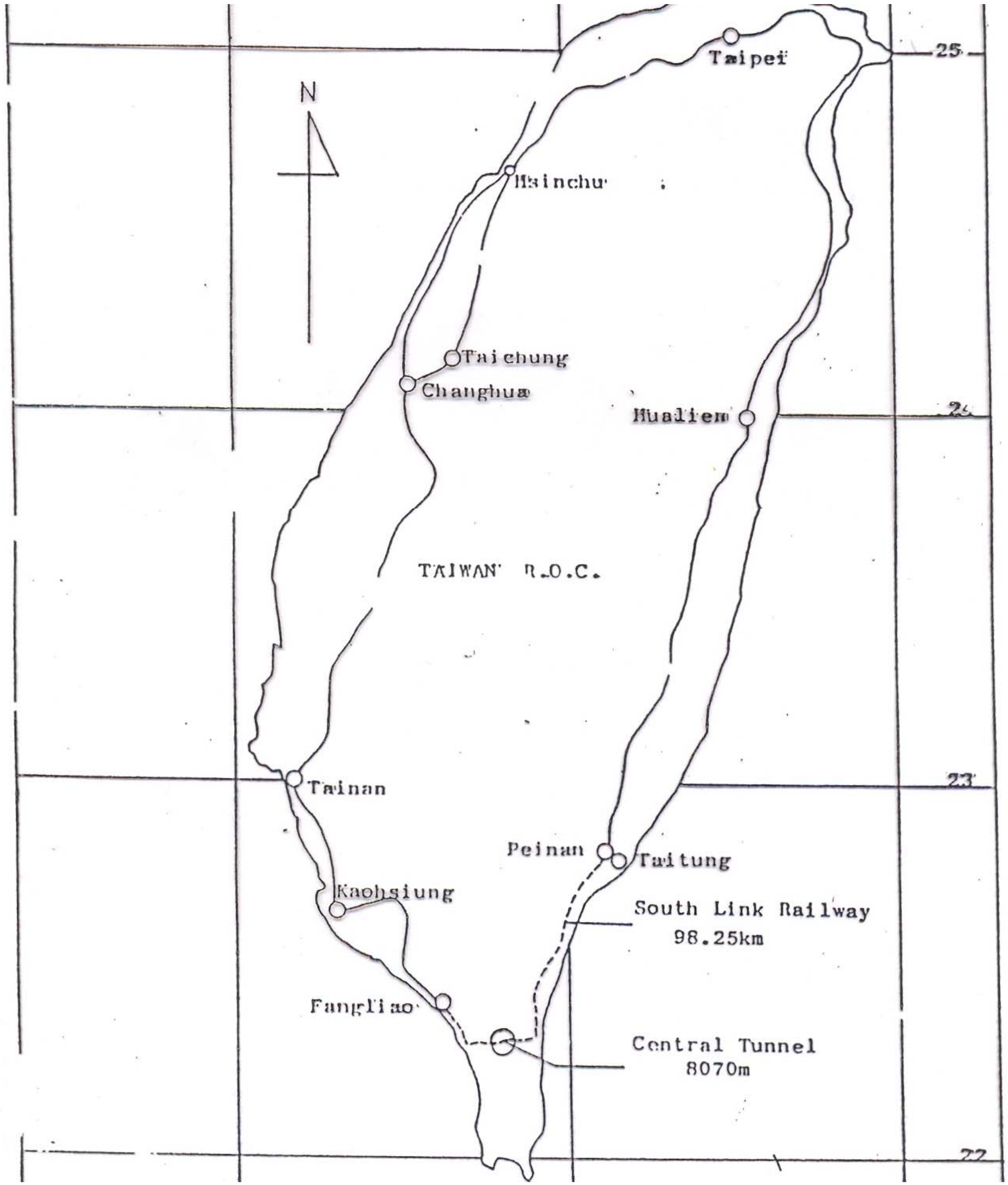


Fig.4.3 Required and Available Support Curves for Rock Support Interaction Analysis of Rock Class V

Central Tunnel- A part of ‘The Southern Link Railway Project’ in South Taiwan

- Overall 8070 m, 10 m diameter horse shoe shaped tunnel through Meta-sedimentary rock excavated by drill and blast method. Period of construction : March 1984 to 1990.


N
Taipei
25
Hsinchu
Taichung
Changhua
Hualien
24
TAIWAN R.O.C.
Tainan
23
Peinan
Taitung
Kaohsiung
South Link Railway
98.25km
Fangliao
Central Tunnel
8070m
22

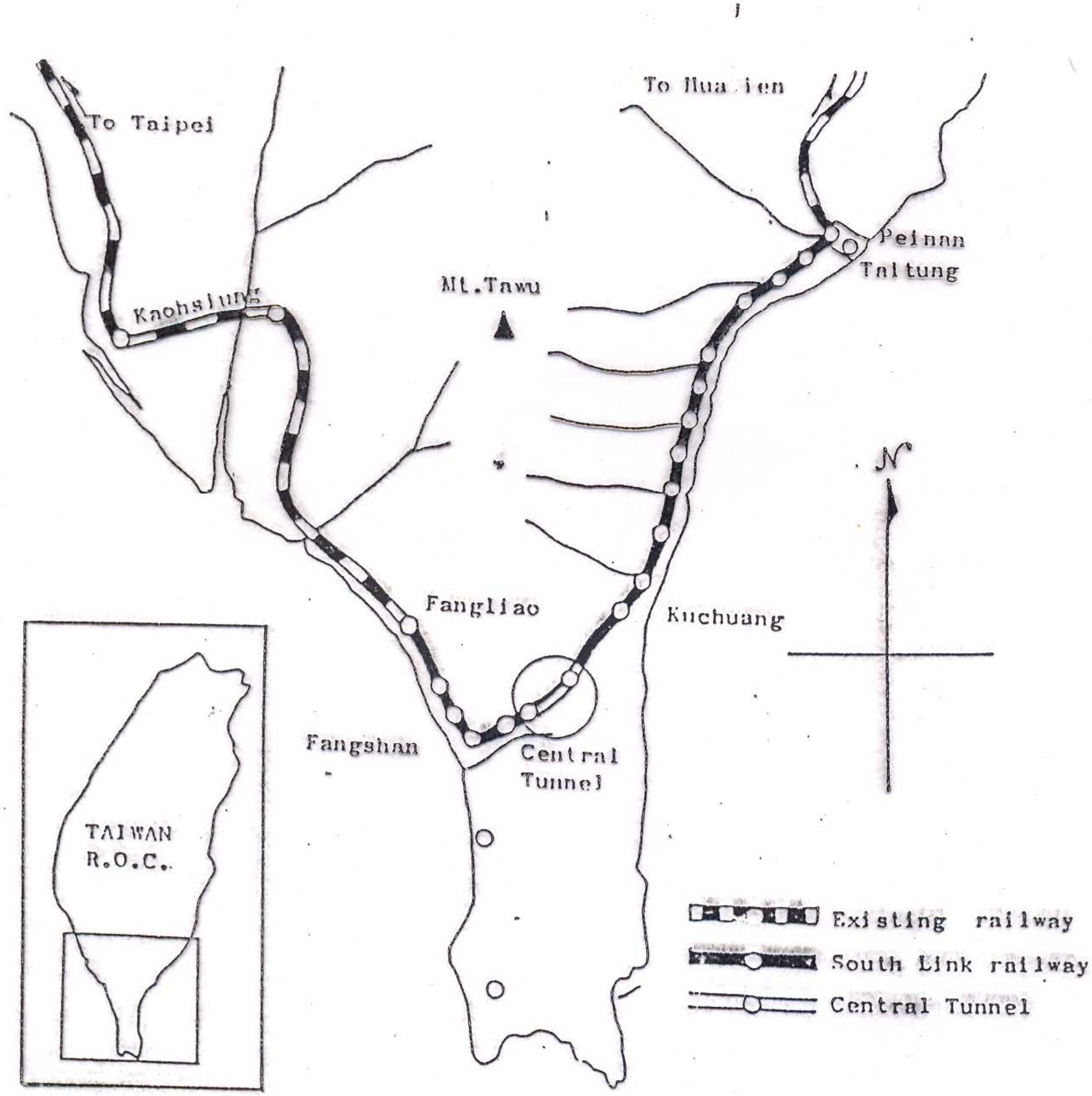
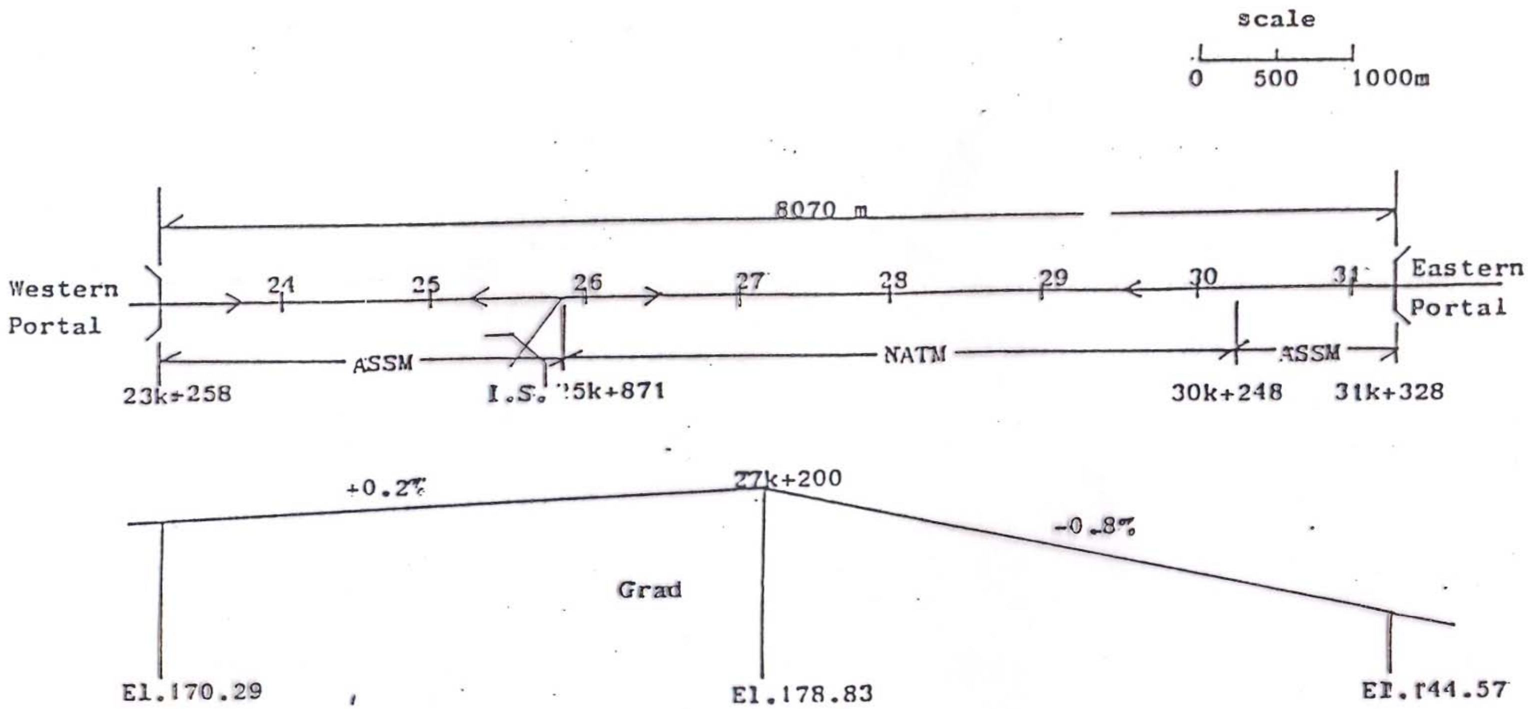


Fig.2.1 Layout of The South Link Railway Project



ASSM : American Steel Sets Method
NATM : New Austrian Tunneling Method

Fig.2.2 Layout of Construction Methods along The Central Tunnel, Length and Elevation

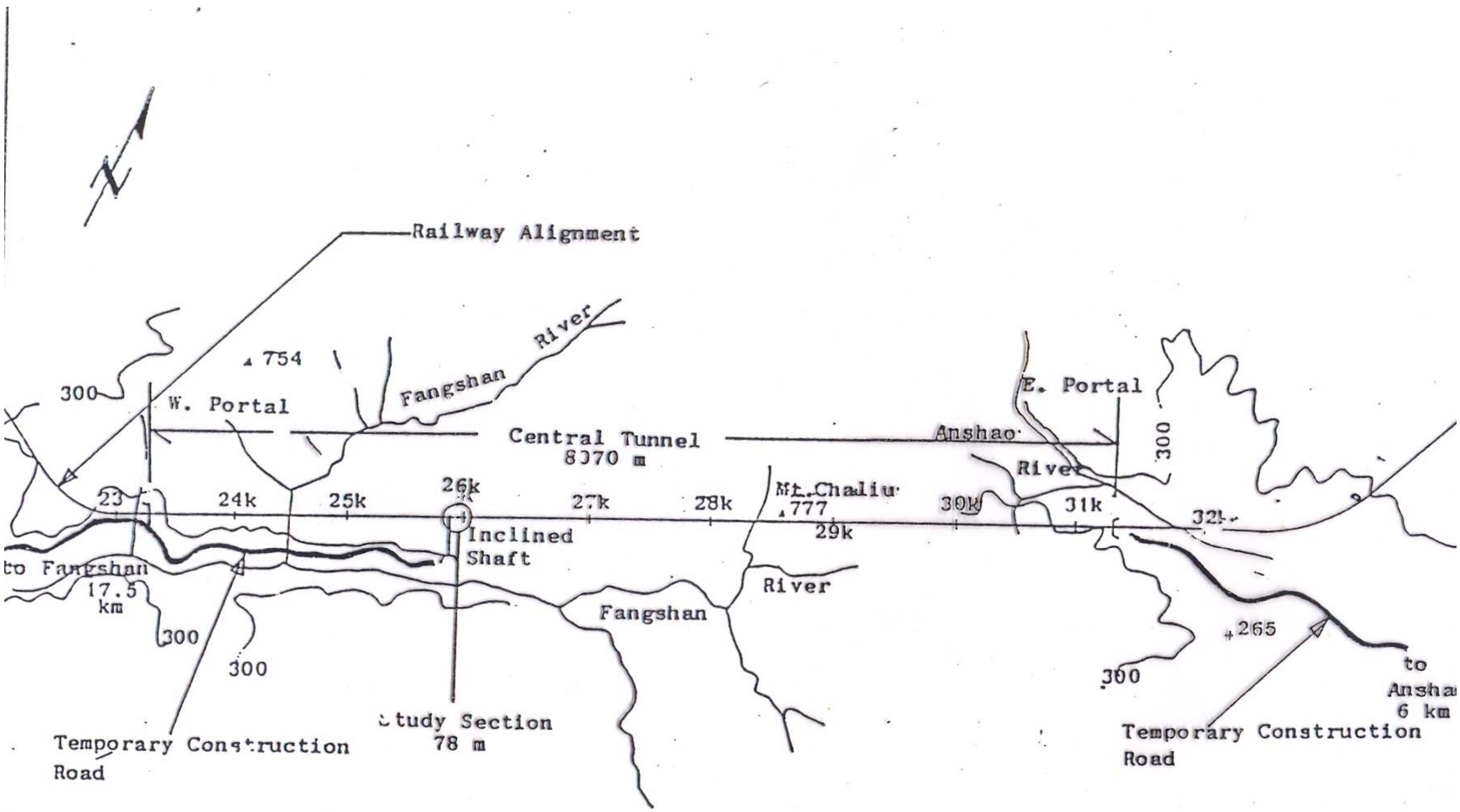


Fig. 1.2 Central Tunnel Area of The South Link Railway

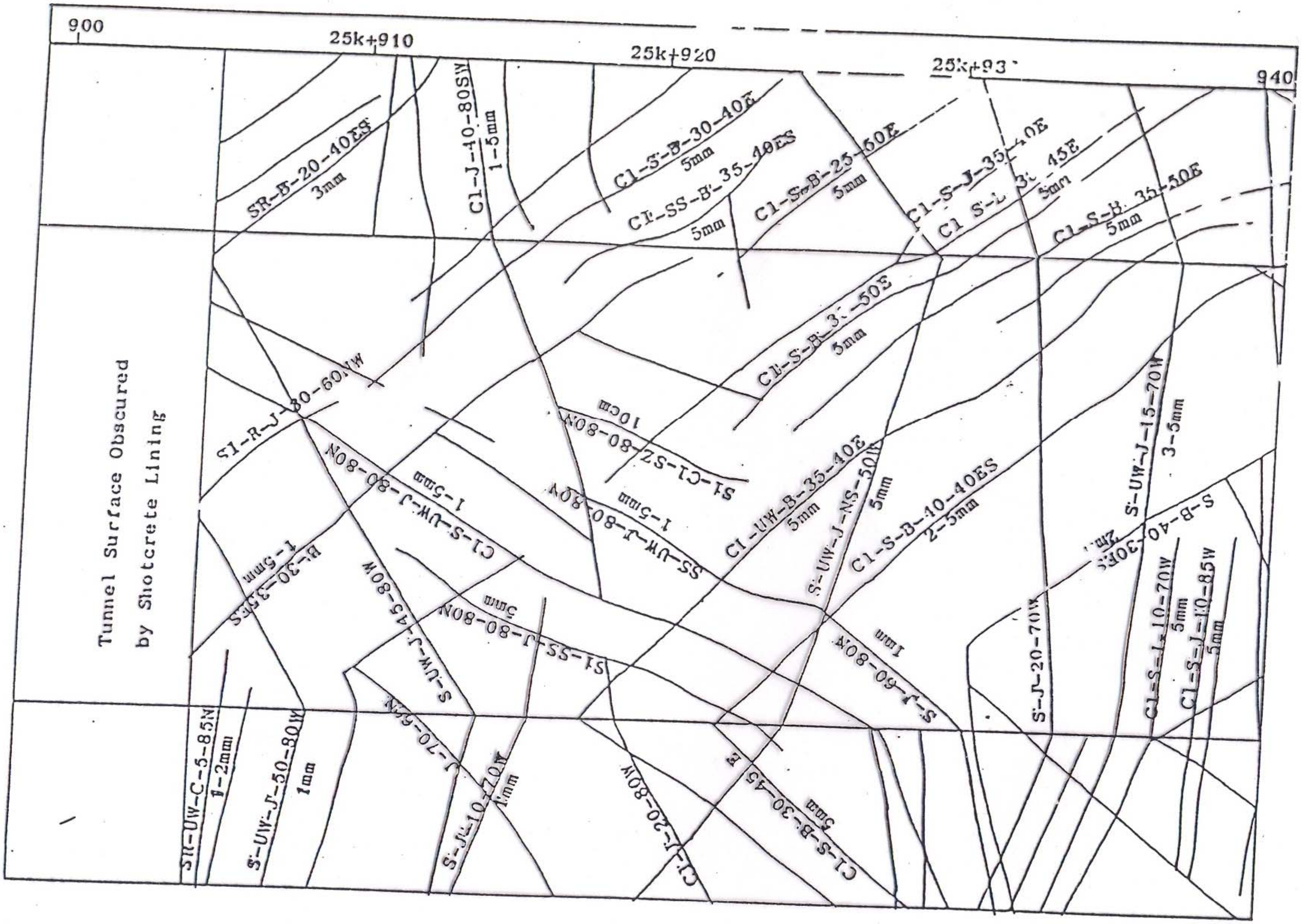


Fig.3.6(a) Engineering Geologic Map of Central Tunnel ,Chainage 25k+905 to +940

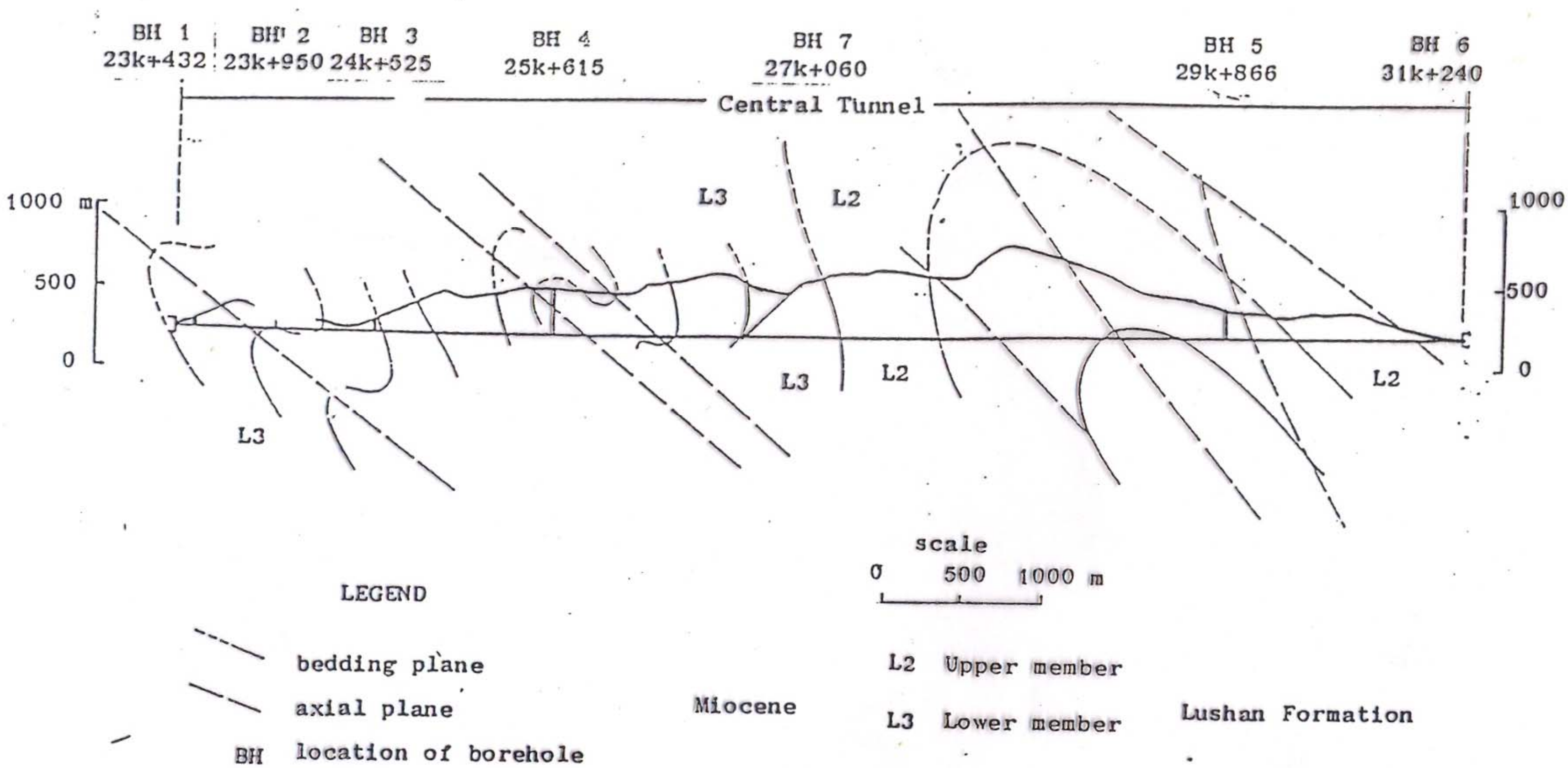


Fig.3.1 Geological Profile of Central Tunnel, Representation of Overturned Bedding, Major Folds, Axial Planes and Location of Borehole. (after Central Geological Survey, 1981)

Purpose of the study

- To correlate four empirical methods.
- To access relationship between support recommended and the geological parameters.
- To compare results of NATM with those of preliminary design.
- To establish most stable and economical support system.

Table 3.2 : Ratings of Various Rock MAss Classifications

Section	RMR	Q	RSR	RQD
25 + 904.8				
25 + 905.8	41	0.867	44	52
25 + 906.8	45	0.833	50	50
25 + 907.8	40	0.917	44	55
25 + 908.8	43	1.08	50	65
25 + 909.8	34	0.292	39	70
25 + 910.8	43	0.625	44	75
25 + 911.8	44	1.333	50	80
25 + 912.8	42	0.833	46	75
25 + 913.8	41	0.583	46	70
25 + 914.8	38	0.750	44	60
25 + 915.8	34	0.281	38	45
25 + 916.8	37	0.313	38	50
25 + 918	37	0.313	38	50
25 + 920.5	36	0.313	38	50
25 + 922	39	0.375	46	60
25 + 923.5	36	0.313	38	50
25 + 925	37	0.313	46	50
25 + 928.1	42	0.667	50	60
25 + 929.9	40	0.556	44	50
25 + 931.4	41	0.611	44	55
25 + 932.9	42	0.667	44	60

Table 4.1 Geologically Similar Subsections Corresponding to Rock Mass Classifications

Tunnel Subsection	RMR	Q	RSR	RQD
(1) Ch. 904.8 - 913.8 m	41	0.818	46	66
(2) Ch. 913.8 - 925 m	37	0.371	41	52
(3) Ch. 925 - 935.9 m	41	0.621	45	56
(4) Ch. 935.9 - 951.5 m	37	0.367	42	44
(5) Ch. 951.9 - 958.4 m	44	0.722	47	50
(6) Ch. 958.4 - 980.4 m	35	0.373	39	43
(7) Ch. 980.4 - 982.4 m	13	0.042	26	15

Table 4.2 Rock Mass Class and Recommended Supports Based on RMR Method

Rock Mass Class	Subsection No.	Shortcrete	Rockbolts (20 mm Fully Bonded	Steel Sets
Fair rock III RMR = 41 - 44	1, 3, 5	5-10 cm in crown and 3 cm in sides	Systematic bolts 4 m long, spaced 1.5-2 m in crown and walls with mesh in crown	None
Poor rock IV RMR = 35 - 37	2, 4, 6	10-15 cm in crown and 10 cm in sides	Systematic bolt 4-5 m long, spaced 1-1.5 m in crown and walls with wiremesh	Light ribs spaced 1.5 m where required
Very poor rock V RMR = 13	7	15-20 cm in crown, 15 cm in sides and 5 cm on face	Systematic bolt 5-6 m long, spaced 1-1.5 m in crown and walls with wiremesh. Bolt invert	Medium to heavy ribs spaced 0.75m with steel logging and forepoling if required; close invert

Table 4.3 Rock Mass Classification According to NGI (Q) System

Q	Subsection No.	Shortcrete	Rockbolts	Steel Sets
Very poor 0.621 - 0.818	1, 3, 5	5-7.5 cm with wiremesh	Untensioned grouted dowels on grid spacing 1.0m	None
Very poor 0.367 - .373	2, 4, 6	7.5-25 cm with wiremesh	None	None
Extremely poor 0.042	7	15-25 cm with wiremesh	None	None

Table 4.4 Support Recommendations Based on RQD

Rock Quality RQD	Subsection No.	Alternative Support Systems		
		Shortcrete	Rockbolts	Steel Sets
Fair 50 - 66	1, 2, 3, 5	4 in or more on crown and sides	Pattern, 3 to 5 ft center	Light to medium sets, 4-5ft center
Poor 43 - 44	4, 6	6 in or more on crown and sides. Combined with bolts	Pattern, 2 to 4 ft center	Medium to heavy sets, 2-4ft center
Very poor 15	7	6 in or more on whole section. Combined with medium to heavy sets	Pattern, 3 ft center	Heavy circular sets, on 2 ft center

Table 4.5 Ratings and Supports Recommended by RSR Method

RSR Rating	Sub-section	RR	Wr kip/ft^2	Alternative Support Systems		
				Shortcrete	Rockbolts	Steel Sets
45-47 Ave. 56	1, 3, 5	36	3.57	3.9 in thick	load 24 kips grid spacing 2.59 ft	8WF40 spacing 3.47 ft
39-42 Ave. 40	2, 4, 6	46	4.54	4.6 in thick	load 24 kips grid spacing 2.[illegible] ft	8WF40 spacing 2.72 ft
26	7	77	7.65	7.1 in thick	load 24 kips grid spacing 1.77 ft	10WF49 spacing 2.17 ft

Table 4.9 Computation of Deformation Modulus

Method	Parameters Used	Modulus Em x 10^4 kg/cm^2		
RQD vs Em COON & MERRIT (1970)	III. RQD = 50-66, Average 58 IV. RQD = 43-52, Average 47 V. RQD = 10-20, Average 15	4.9	2.1	< 0.7
RQD vs Em/El BIENIAWSKI (1978)	III. RQD = 58, Em/El = 0.17, El = 18.8 IV. RQD = 47, Em/El = 0.14, El = 18.8 IV. RQD = 15, Em/El = 0.11, El = 18.8	3.2	2.6	2.1
RMR vs Em SARAFIN and PEREIRA (1983)	III. RMR = 41-44, Average 42 IV. RMR = 35-37, Average 36 V. RMR = 7-20, Average 13	6.4	4.6	1.2
RMR vs Em CHAPPLE and MAURICE (1980)	III. RMR = 41 IV. RMR = 36 V. RMR = 1[illegible]	2.8/ 11.2	1.9/8.6	0/0
JOINT FRE- QUENCY vs Em SINGH (1973)	III. RQD = 58, n=9, r=0.25 IV. RQD = 47, n=108, r=0.25 V. RQD = 15, n=16.4, r=0.6	5.8	5.1	1.7

Table 4.10 Material Constants of Jointed and Broken Rock Mass

Rock Class	III	IV	V
Average RMR	51	31	10
m	0.38	0.084	0.018
S	0.0004	0.00002	0.000001
Lowest RMR	41	27	7
mr	0.18	0.063	0.014
Sr	0.00009	0.000009	0

Table 4.11 Support Requirements Based on Rock-Support Intersection Analysis

Rock Class RMR	ubsection No.	Reinforced Shotcrete	Grouted Rockbolt (25 mm dia, 10 tons)	Steel Sets
III	1, 3, 5	12.5 cm with wiremesh ϕ5 x100x100 mm	l = 3 m spacing 1.5x2.0 m	H100 x 100 max. spacing 2.0 m
IV	2, 4, 6	25 cm with wiremesh,	l = 4 m spacing 1.2x1.5 m	H125 x 125 max. spacing 1.5 m
V	7	65 cm (σc = 240 kg/cm^2), with wiremesh	l = 5 m 0.8 m on grid pattern	H200 x 200 max. spacing 0.8 m

Table 4.12 Input Data for Rock-Support Intersection Analysis

Parameters	Rock Class III	Rock Class IV	Rock Class V
Rock MAss			
uniaxial compressive strength of intact rock (kg/cm^2)	552	552	552
material constant for original rock mass (m)	0.38	0.084	0.018
material constant for original rock mass (S)	0.0004	0.00002	0.000001
modulus of deformation for rock mass	61000	48000	14000
poission's ratio	0.2	0.2	0.2
material constant for broken rock mass (mr)	0.18	0.063	0.014
material constant for broken rock mass (Sr)	0.00009	0.000009	0
unit weight of broken rock mass (kg/cm^3)	0.0027	0.0027	0.0027
in-situ stress (kg/cm^2)	59	59	59
radius of tunnel	510	520	525
Shotcrete Lining			
modulus of elasticity Ec (kg/cm^2)	200000	200000	200000
poisson's ratio	0.25	0.25	0.25
compressive strength (kg/cm^2)	210	210	240
thickness (cm)	12.5	25	65
Blocked Steel Sets			
flange width (cm)	10	12.5	20
section depth (cm)	10	12.5	20
section area (cm^2)	21.9	30.31	63.53
moment of inertia (cm^4)	383	847	4720
Young's modulus of steel (kg/cm^2)	2070000	2070000	2070000
Yield strength of steel (kg/cm^2)	2500	2500	2500
Young's modulus of blocking material (kg/cm^2)	200000	200000	200000
Rock Bolts			
bolt diameter (cm)	2.54	2.54	2.54
Young's modulus of bolts (kg/cm^2)	2070000	2070000	2070000
anchor stiffness (cm/kg)	0	0	0
pull out strength (tons)	10	10	10

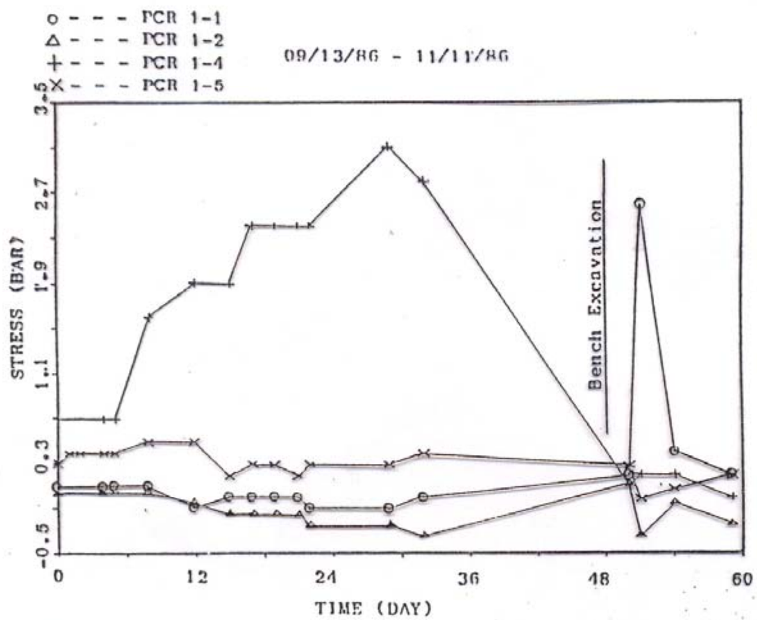


Fig.3.13(a) Results of Radial Pressure Cell Measurement

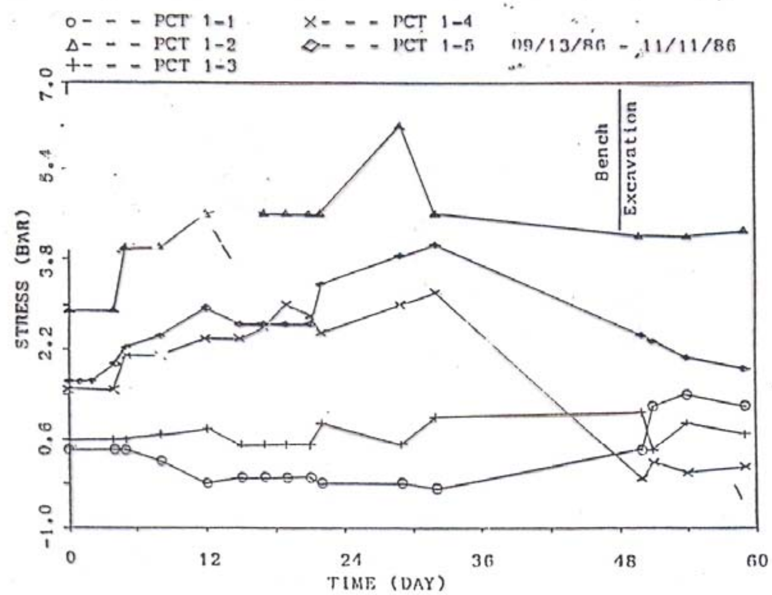


Fig.3.13(b) Results of Tangential Pressure Cell Measurement

Table 5.1 Summary of Correlations Between Q, RMR and RSR

	RMR = a + b log Q			RSR = c + d log Q			RSR = e+f.RMR			No. of Cases
	a	b	r	c	d	r	e	f	r	
BIENIAWSKI, (1976)	44	20.7	-	-	-	-	-	-	-	111
RUTLEDGE and PRESTON, (1977)	43	13.5	-	46.5	13.3	-	12.4	0.77	-	-
Pando N.*	58.8	13.5	0.82	56.28	11.5	0.12	13.5	0.74	0.87	37
Negron N.*	47.96	16.0	0.73	51.9	6.68	0.36	19.5	0.61	0.71	31
Negron S.*	54.6	12.3	0.89	52.87	9.55	0.82	10.6	0.77	0.93	65
Barrios S.*	54.0	14.97	0.92	54.11	8.66	0.66	16.1	0.68	0.86	17
Chiew Larn**	-	-	-	62	21.7	-	15.2	0.83	-	9
Huai Saphan Hin	48.1	18.9	0.83	52	17.6	0.86	9.9	0.88	0.98	15
Central Tunnel	44.5	18.3	0.94	47.5	1[illegible].7	0.88	13	0.77	0.89	59

Note: r = correlation coefficient
* correlation by MORENO (1982)
** correlation by RANASOORIYA (1985)
+ correlation by LASAO (1986)

Table 3.2 Comparison of Rock Mass Classifications Applied at the Central Tunnel

Subsection	Geomechanic Classification RMR		Q System	
	Class	Support	Class	Support
1, 3, 5	III Fair rock RMR = 41-44	5-10 cm shotcrete in crown, 3 cm in sides; systematic grouted bolts (20 mm dia.) spaced 1.5-2 m, length 4 m, with mesh in crown	Very poor rock Q = 0.621-0.818	5-7.5 cm shotcrete with wiremesh, untensioned grouted dewels on grid spacing 1 m
2, 4, 6	IV Poor rock RMR = 35-37	10-15 cm shotcrete in crown, 10cm in sides; systematic grouted bolts spaced 1-1.5 m, length 4-5 m plus wiremesh; light ribs at 1.5 m where required	Very poor rock Q = 0.367-0.373	7.5-25 cm with wiremesh
7	V Very poor rock RMR = 13	15-20 cm shotcrete in crown, 15 cm in sides and 5 cm on face; systematic grouted bolts spaced 1-1.5m, length 5-6 m plus wiremesh, bolt invert medium to heavy ribs at 0.75 m with steel logging and forepoling if required; closed invert	Extremely poor rock Q = 0.042	15-25 cm with wiremesh

Table 5.2 (Cont'd)

Subsection	New Austrian Tunneling Method		Rock Support Interaction Analysis	
	Class	Support	Class	Support
1, 3, 5	III	12.5 cm shotcrete with mesh[1], systematic grouted bolts 3 m long[2] spaced 1.5 x2.0 m, plus ribs H100 spacing 2.0 m	III	Same as NATM's class
2, 4, 6	IV	15 cm shotcrete with mesh, face 5 cm where required; systematic grouted bolts 4 m long, spaced 1.2x1.5 m plus ribs H125 spacing 1.5 m fore-poling occasionally[3]	IV	25 cm shotcrete with mesh, systematic grouted bolts 4 m long, spaced 1.2x1.5 m plus ribs H125 spacing 1.5 m
7	V	20 cm shotcrete with mesh, face 5 cm, invert 10 cm if required; systematic grouted bolts 5 m long; spaced 1.0x1.0 m plus ribs H150, spacing 1.0 m fore-poling c/c 30 cm	V	65 cm shotcrete (σ_c = 240 kg/cm^2) with mesh; systematic grouted bolts 5 m long, spaced 0.8x0.8 m plus ribs H200, spacing 0.8 m

Notes: [1] wiremesh ϕ5 x 100 x 100 mm
[2] grouted rockbolts 25 mm dia., working load 10 tons
[3] fore-poling ϕ4.2 x 300 cm

Table 5.2 (Cont'd)

Subsection	RSR Classification		RQD Classification	
	Class	Support	Class	Support
1, 3, 5	RSR = 45-47	10 cm shotcrete or systematic rockbolts (25 mm dia.) at 0.8 m or steel ribs 8WF40 at 1.0 m	Fair RQD = 50-66	10 cm or more shotcrete or systematic bolts spaced 0.9-1.5 m or light to medium steel ribs at 1.2 - 1.5 m partial mesh required
2, 4, 6	RSR = 39-42	12 cm shotcrete or systematic rockbolts at 0.7 m or steel ribs 8WF40 at 0.8 m	Poor RQD = 43-44	15 cm or more shotcrete plus bolts or systematic bolts spaced 0.[illegible]-1.2 m or medium to heavy ribs at 0.6-1.2 m more partial mesh required
7	RSR = 26	18 cm shotcrete or systematic rockbolts at 0.5 m or steel ribs 10WF49 at 0.65m	Very poor RQD = 15	15 cm or more shotcrete plus medium to heavy ribs or systematic bolts spaced 0.9 m or heavy circular ribs at 0.6 m mesh requirement 100%.

Table 5.3 Actual Supports of the Central Tunnel

Rock Class	Steel Ribs	Shotcrete[1]	Rock Bolt[2]	Forepoling[3]
III (Type C)	H150, spaced 1.5 - 1.8 m	15 cm	3 m, spaced 1.5 x 1.7 m	-
IV (Type B)	H150, spaced 1.2 - 1.5 m	15 cm Face 5 cm if required	4 m, spaced 1.2 x 1.5 m	Occasional if required
V (Type A)	H150, spaced ≤ 1.0 m	20 cm invert 10 cm face 5 cm	5 m, spaced 1.0 x 1.5 m	c/c 30 cm where required

Remarks: [1] The strength of shotcrete after 28 days is 210 kg/cm^2, and wiremesh of ϕ6x100x100 mm is used for each rock class

[2] Rock bolt = diameter ϕ25 mm, pull resistance 10 tons

[3] Forepoling = ϕ4.2x300 cm

CONCLUSIONS

- Final ratings : RSR 34-88
  RMR 27-87
  Q 0.06-57.6
- Supports: RSR Most Expensive
  RMR Less Expensive
  Q Least Expensive

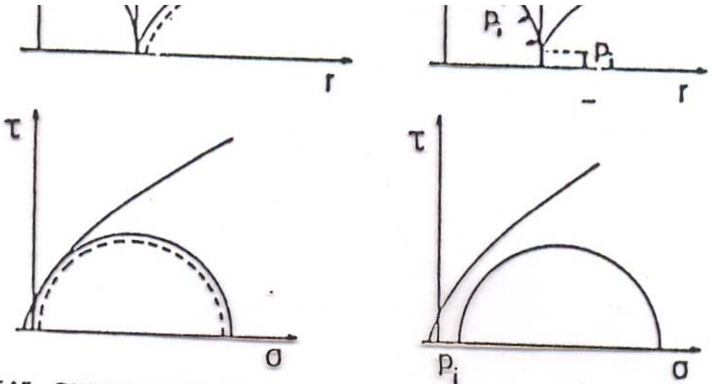


Fig. 10 UNIAXIAL STRESS CONDITIONS SHOULD BE PREVENTED.

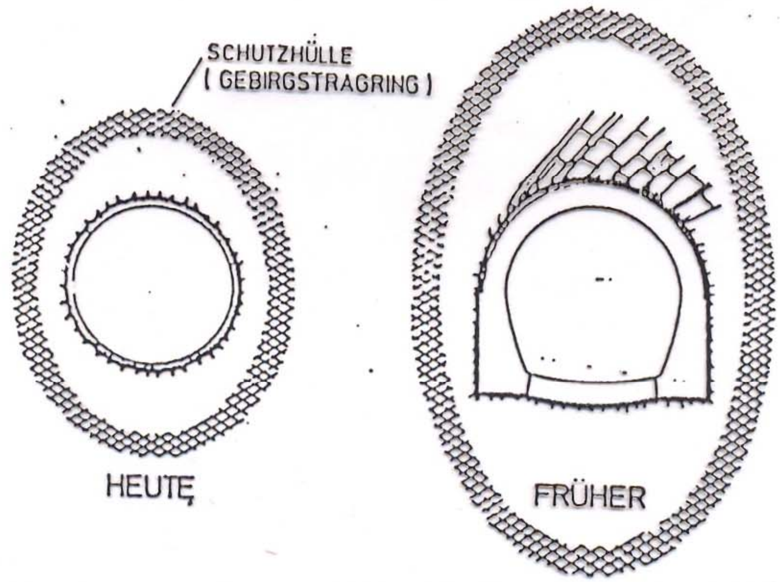
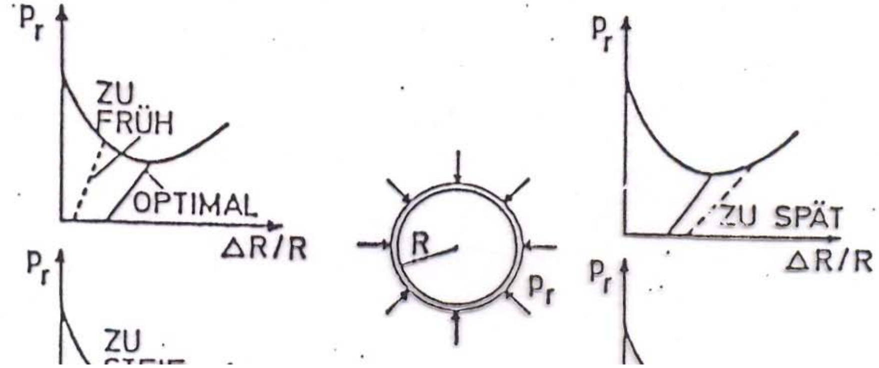


FIG. 11

MOBILIZING OF THE PROTECTIVE RING (ROCK CARRYING RING) WITHOUT STRENGTH REDUCTION.



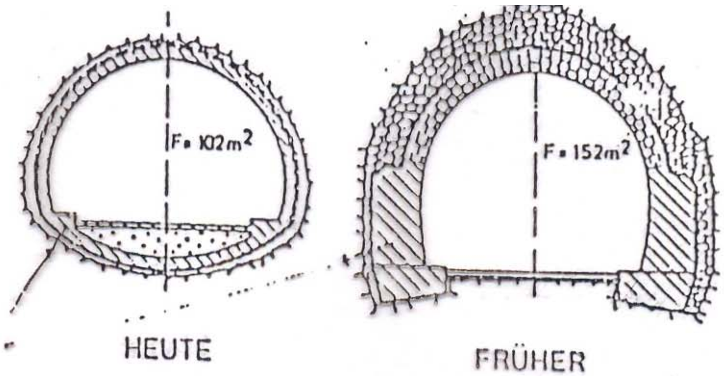


Fig. 28. INTERNAL SHELL SHOULD ALSO BE THIN. CONNECTION OF THE FORCES IS USEFUL BUT FRICTIONLESS.

Only in case of cohesive soils the internal shell is used for stabilization in addition to external shell

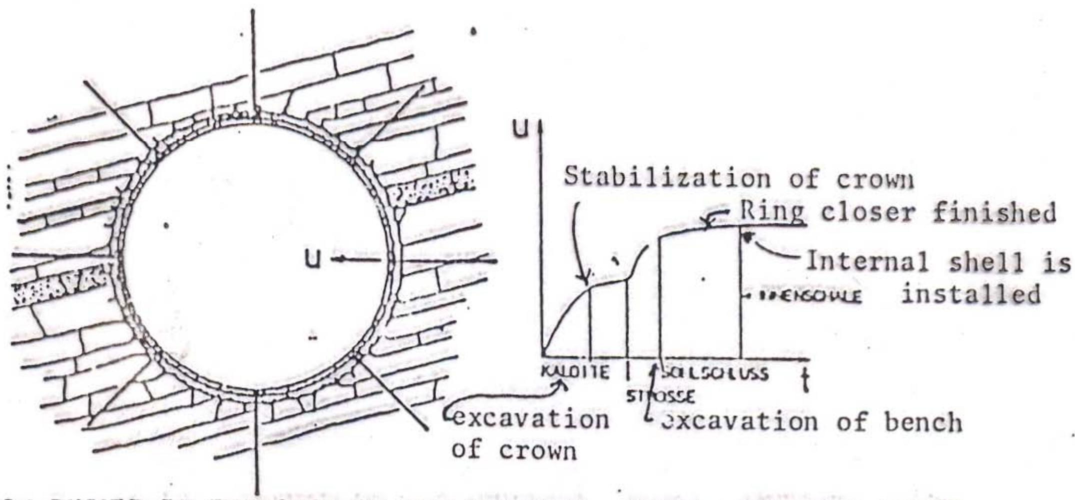


Fig. 29. STABILIZATION SHOULD BE EFFECTED BY THE EXTERNAL SHELL, INTERNAL SHELL INCREASES THE SAFETY. IN CASE OF AGGRESIVE WATER THE INTERNAL SHALE

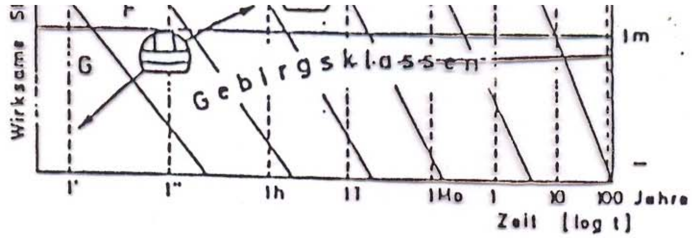


FIGURE 13

CORRECT ESTIMATION OF THE SPECIFIC FACTOR OF TIME IS IMPORTANT.

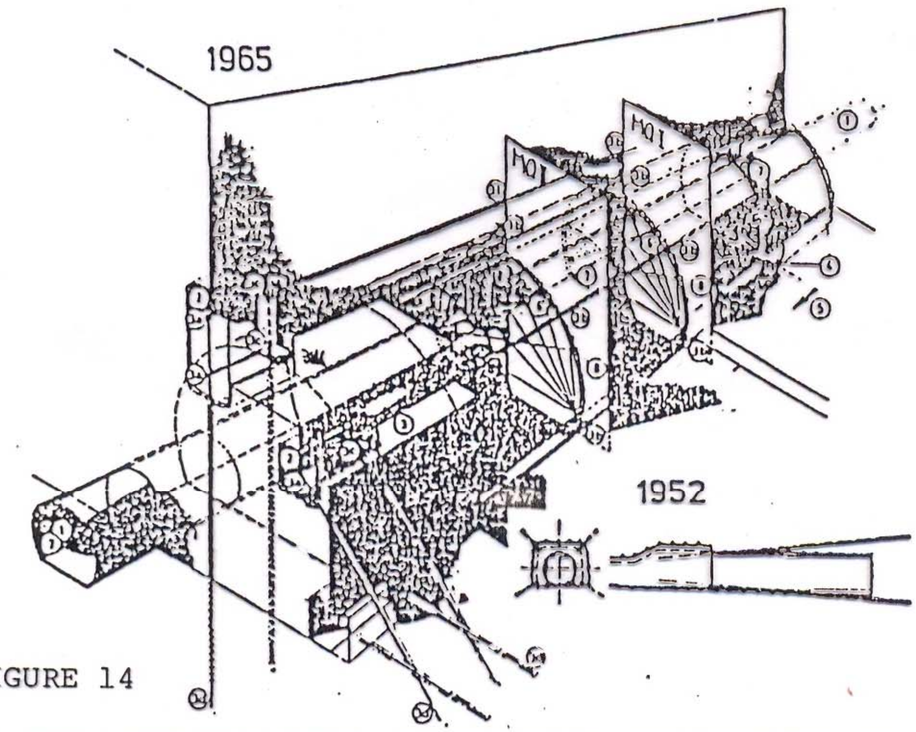
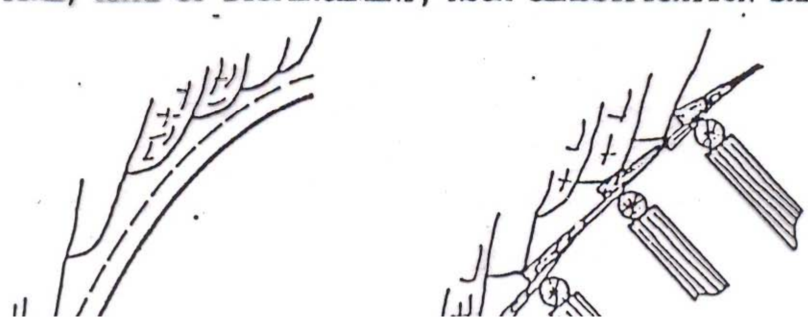


FIGURE 14

FOR THIS LABORATORY TESTS, IN-SITU TESTS, MEASUREMENTS ARE NECESSARY.
STAND UP TIME, RATE OF DISPLACEMENT, ROCK CLASSIFICATION SHALL BE USED.



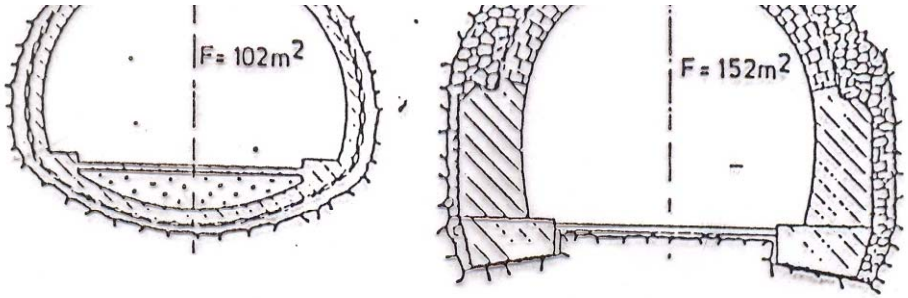


FIG. 16 HEUTE FRÜHER

SUPPORT SHOULD CONSIST OF THIN SHELLS WHICH ARE FLEXIBLE TO BENDING. ABILITY TO CARRYING BENDING MOMENTS AND BENDING FAILURE IS REDUCED.

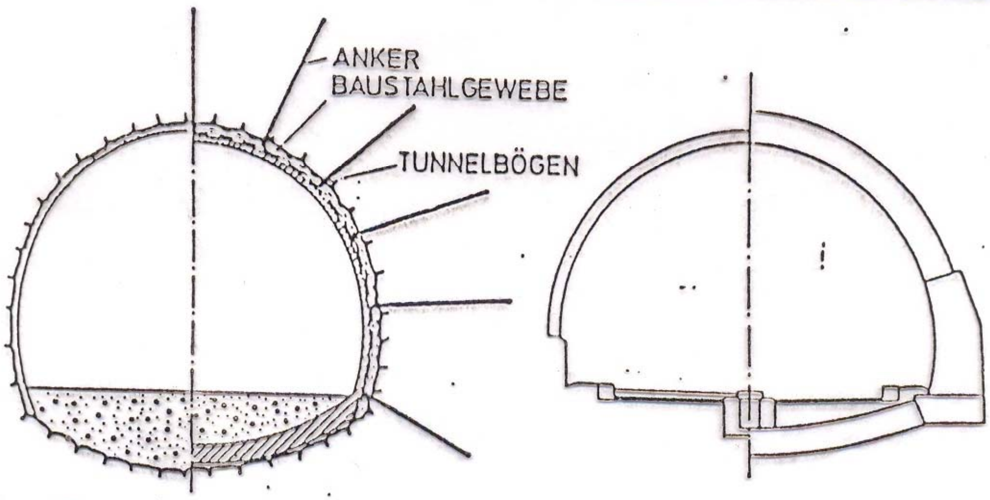
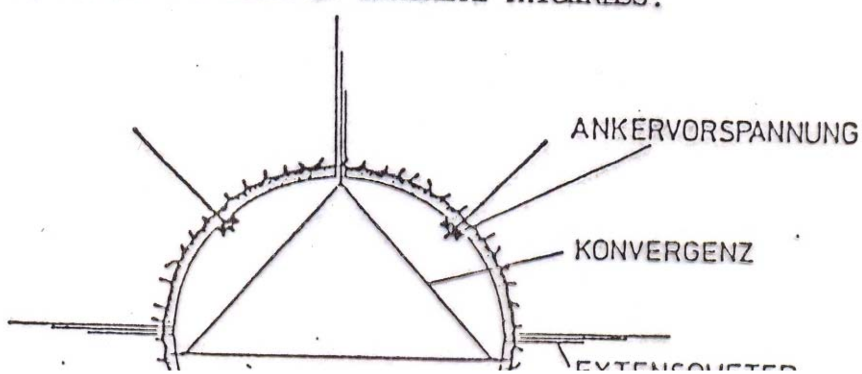


FIG. 17 HEUTE FRÜHER

ADDITIONAL SUPPORT SHOULD BE PROVIDED BY WIRE MASHES, STEEL ARCHES AND ANCHORAGE. NOT BY INCREASE OF CONCRETE THICKNESS.



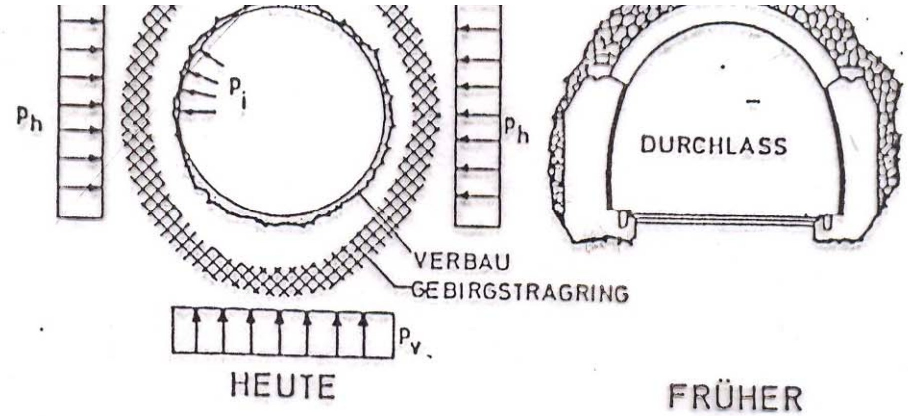


Fig. 19 ACCORDING TO STATICAL PRINCIPLES THE TUNNEL IS A TUBE WHICH CONSISTS OF THE ROCK CARRYING RING AND THE SUPPORT, NOT A CONDUIT.

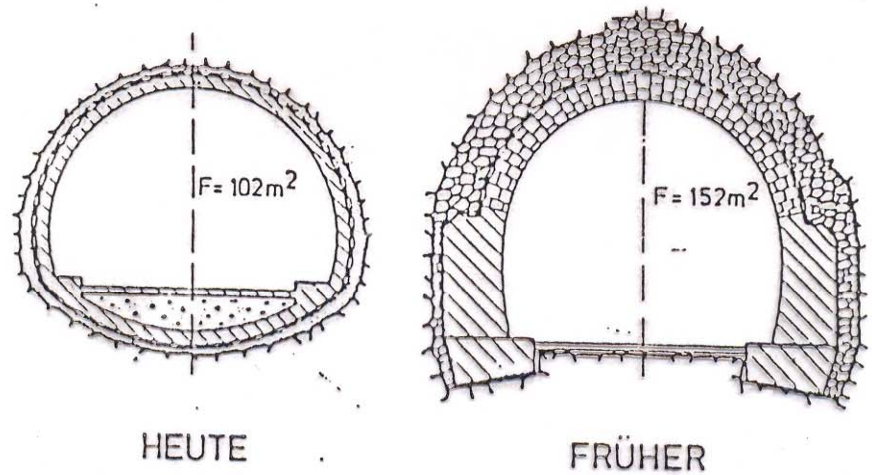
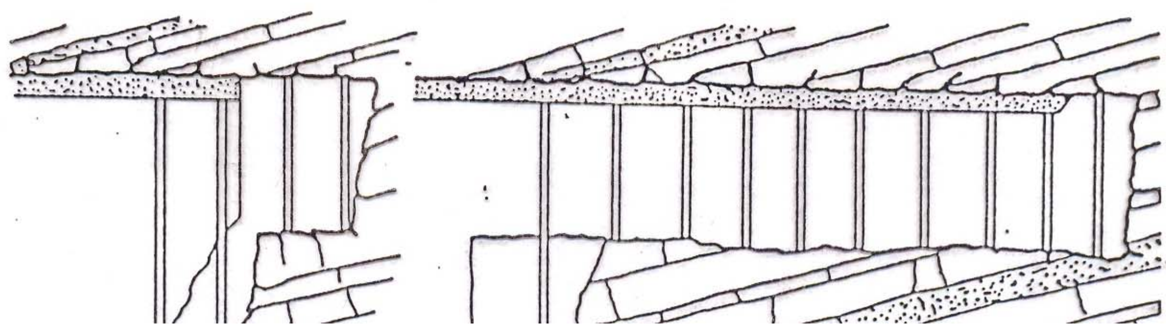
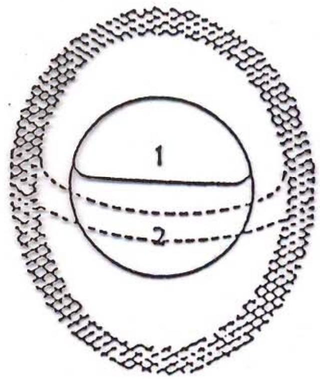


Fig. 20 THEREFORE CLOSURE OF THE RING IS NECESSARY IF NOT CAUSED BY THE BEDROCK. THE EFFECT IS ONLY GIVEN WITHOUT A GAP.





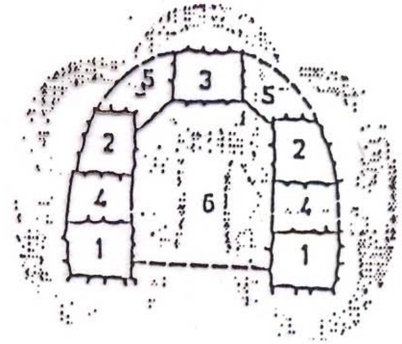
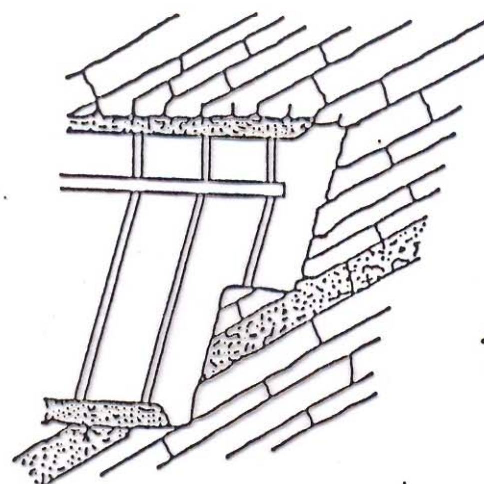


FIG. 22 HEUTE FRÜHER

FULL FACE HEADING HELPS TO KEEP ROCK STRENGTH. MANY PARTIAL HEADINGS REDUCE ROCK STRENGTH ACCORDING TO STRESS SUPER-POSITION.



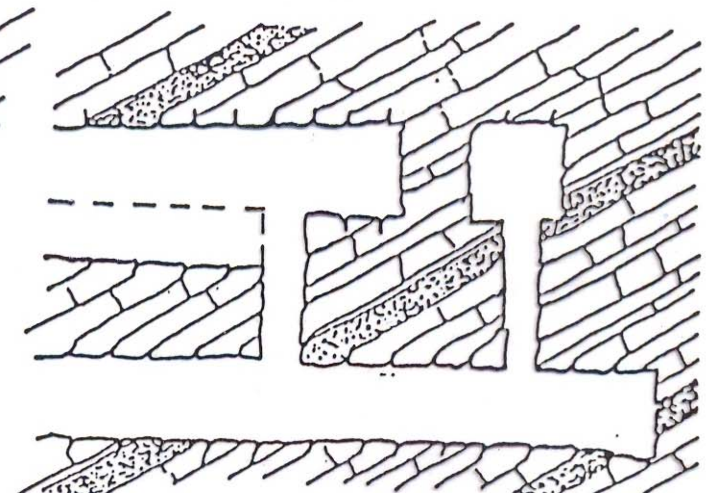
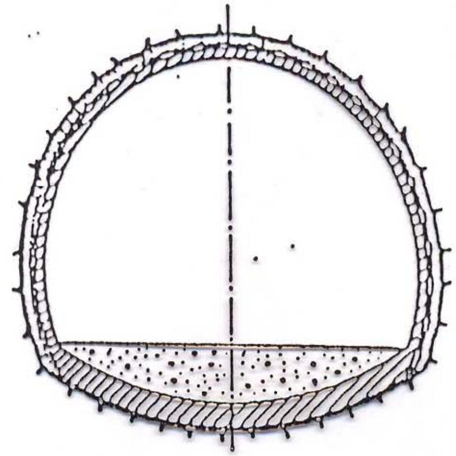


FIG. 23 HEUTE FRÜHER

PROCEDURE OF THE CONSTRUCTION IS IMPORTANT FOR SAFETY OF THE STRUCTURE. VARIATION OF LENGTH OF A ROUND, TIMING OF SUPPORT AND RING CLOSURE, LENGTH OF THE CROWN , AND LINING RESISTANCE ARE USED TO HELP THE PROCEDURE OF SELF



There corners should be avoided
because they create concentration
of stresses

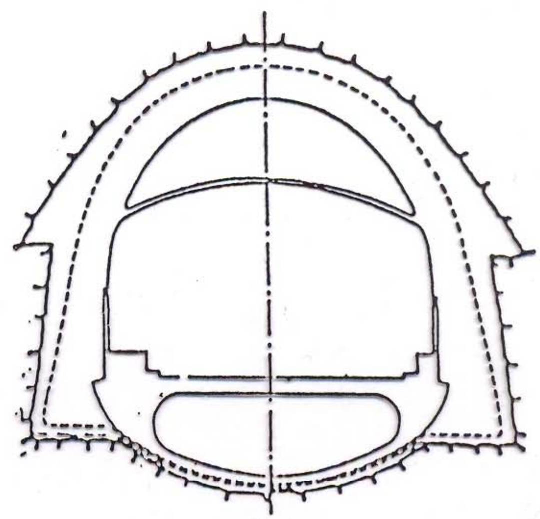


Fig. 24 SMOOTHLY ROUNDED SHAPES HELP TO PREVENT STRESS CONCENTRATIONS.

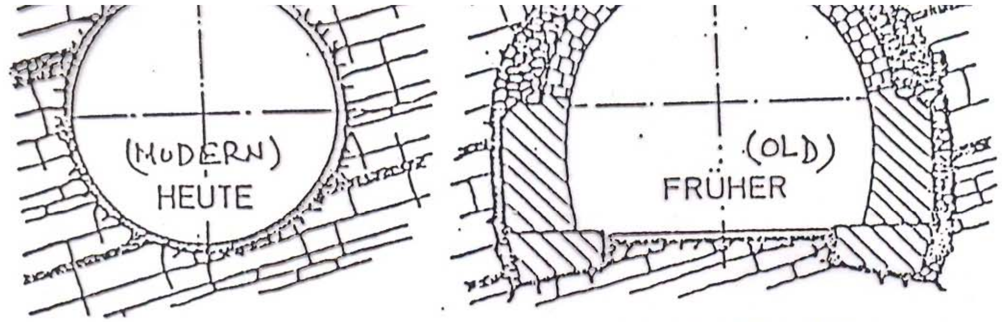


Fig. 7 THE MAIN CARRYING MEMBER IS THE ROCK.

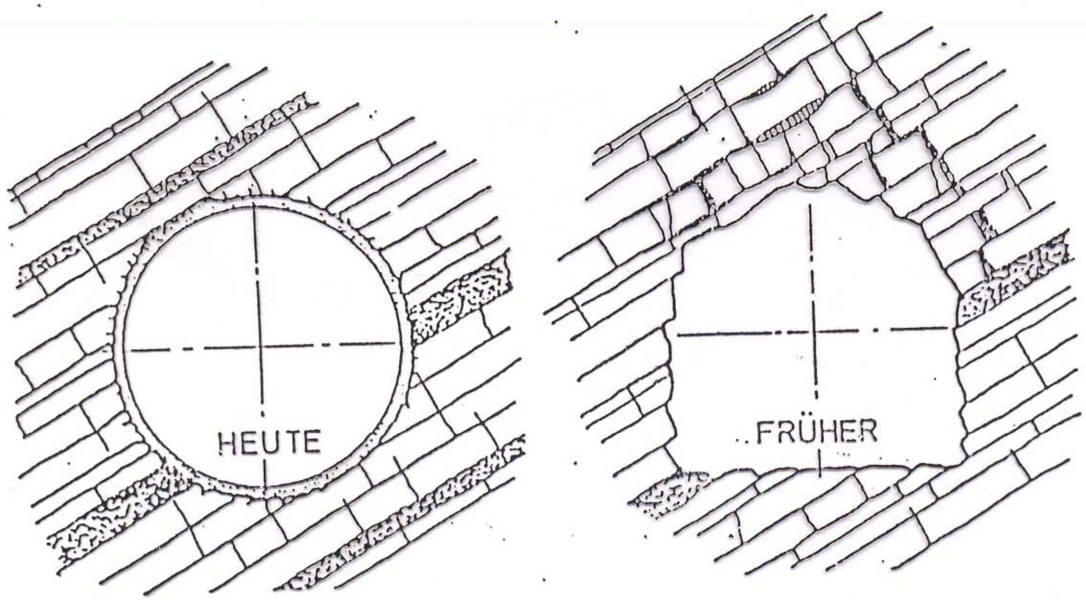
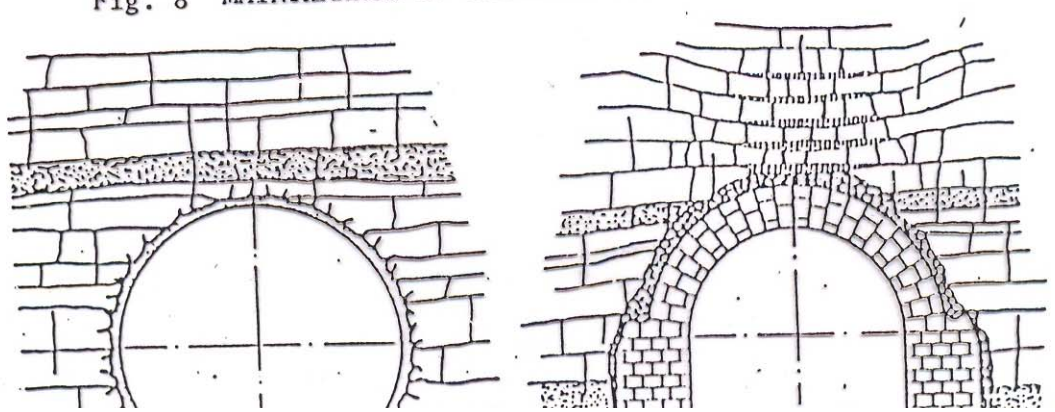


Fig. 8 MAINTENANCE OF ORIGINAL ROCK STRENGTH.



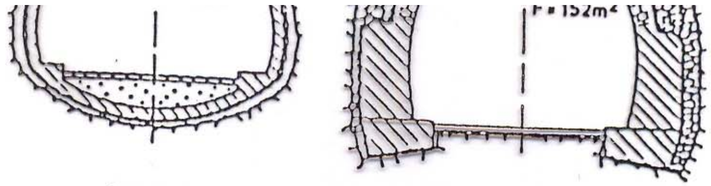


FIG. 25

HEUTE FRÜHER

INTERNAL SHELL SHOULD ALSO BE THIN. CONNECTION OF THE FORCES IS USEFUL BUT FRICTIONLESS.

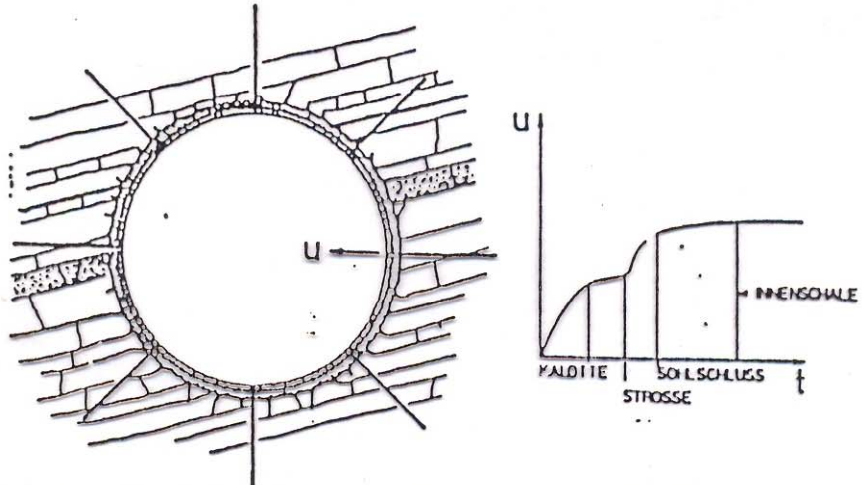
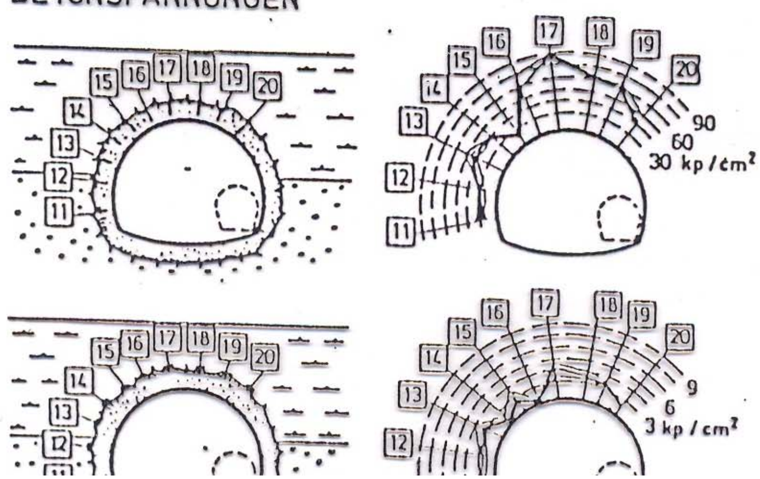


FIG. 26

STABILIZATION SHOULD BE EFFECTED BY THE EXTERNAL SHELL. INTERNAL SHELL INCREASES THE SAFETY. IN CASE OF AGGRESIVE WATER THE INTERNAL SHALE MUST BE CAPABLE OF STABILIZING THE SYSTEM BY ITSELF. PERMANENT SUPPORT OF ANCHOR IS ONLY GIVEN IF THEY ARE PROTECTED AGAINST CORROSION.

BETONSPANNUNGEN



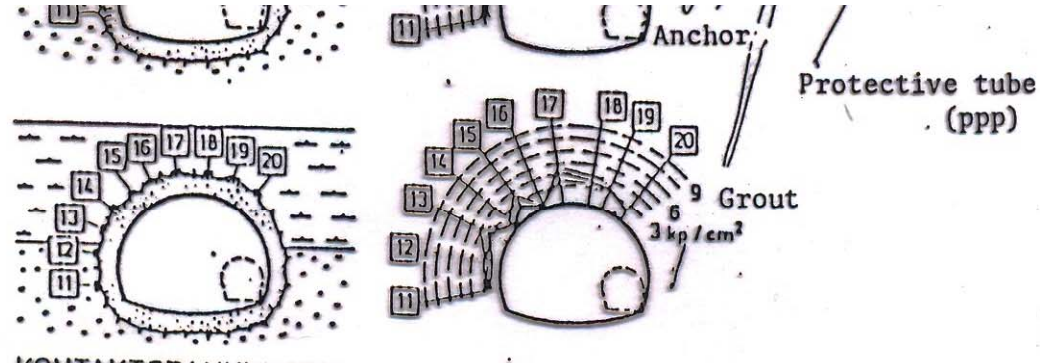
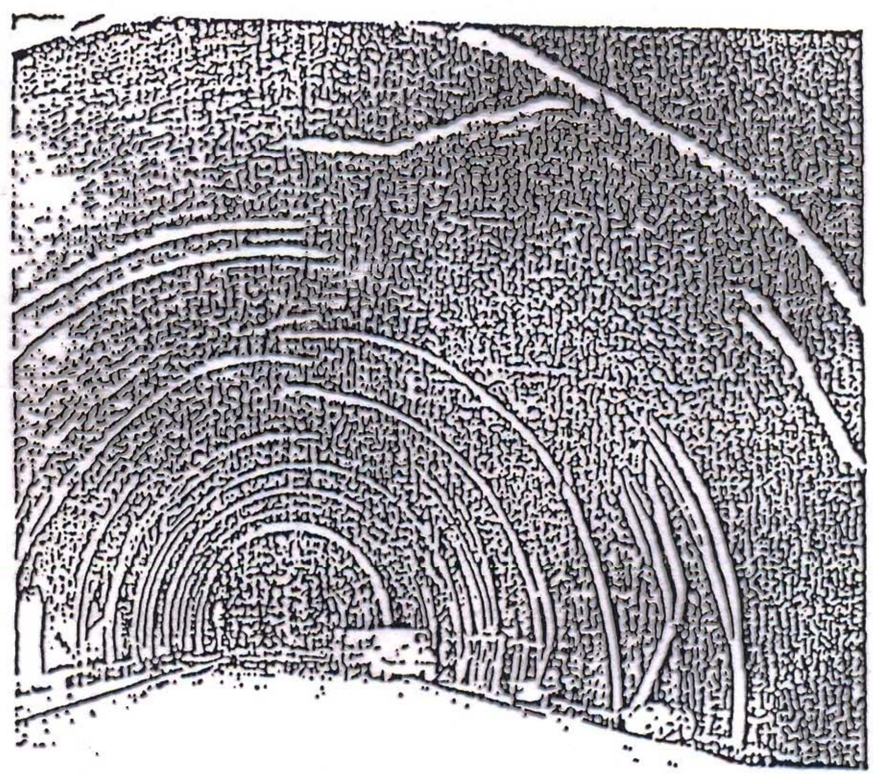


Fig. 30 CONTROL AND DIMENSIONING OF THE TOTAL CONSTRUCTION WITH THE HELP OF (TANGENTIAL) CONCRETE STRESSES AND (RADIAL) CONTACT STRESSES AS WELL AS DISPLACEMENT MEASUREMENS.



$q_a = q_c \cdot \frac{N_j}{4} \cdot \frac{N_d}{4}$

TABLE V - SYMBOLS FOR BASIC GEOTECHNICAL DESCRIPTION

Interval for item (2) & (3) in cm	Layer thickness	Fracture Intercept	Uniaxial com. strength		Angle of Friction	
			kg/cm^2	Symbol	Degrees	Symbol
(1)	(2)	(3)	(4)	(5)	(6)	(7)
200	L_1	F_1	2000	S_1	> 45	A_1
60-200	L_2	F_2	600-2000	S_2	35-45	A_2
20-60	L_3	F_3	200-600	S_3	25-35	A_3
6-20	L_4	F_4	60-200	S_4	15-25	A_4
6	L_5	F_5	60	S_5	< 15	A_5

Quartz L_2 f_4 S_3 A_2