Excavation of the HK Cavern

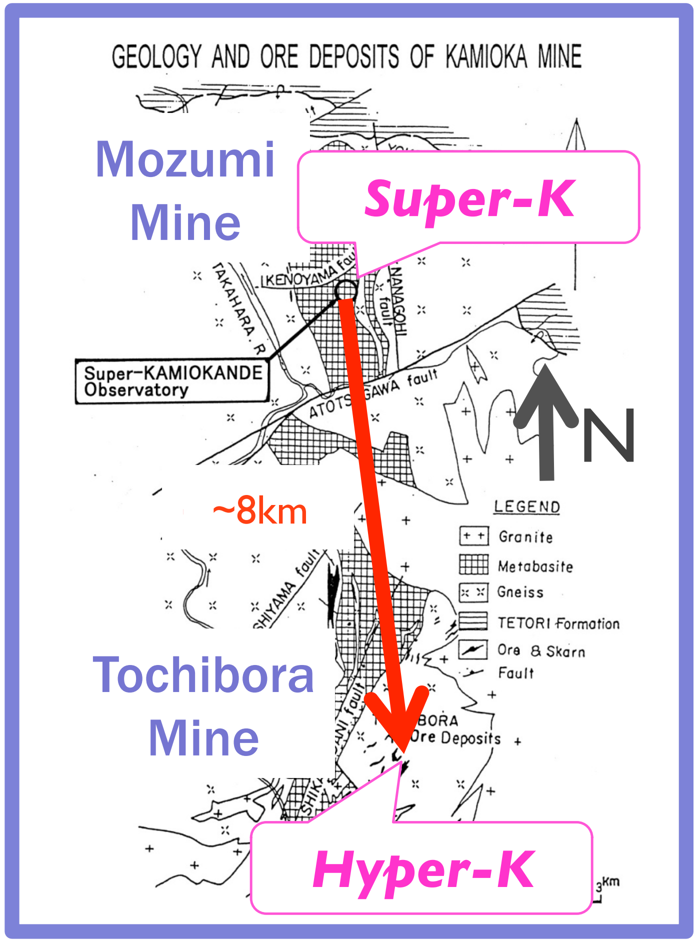
Masato SHIOZAWA
Kamioka Observatory, Institute for Cosmic Ray Research, U of Tokyo, and
Kamioka Satellite, Kavli Institute for the Mathematics and Physics of the Universe, U of Tokyo

Open Hyper-K meeting, August-22-2012

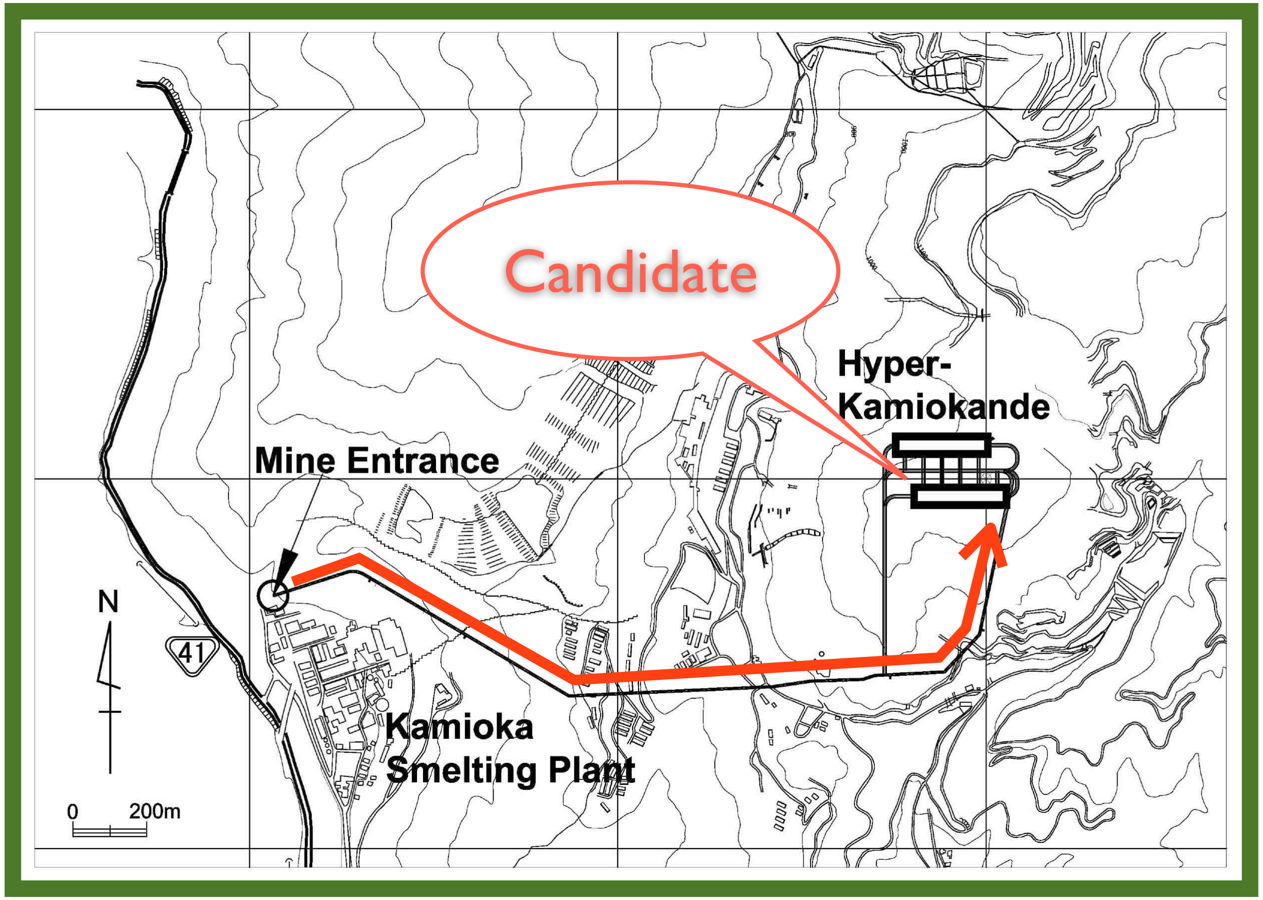
Contents

- Summary of baseline design
  - Geological survey results
  - Cavity stability study, support design
  - Scheduling excavation process
- Ongoing study

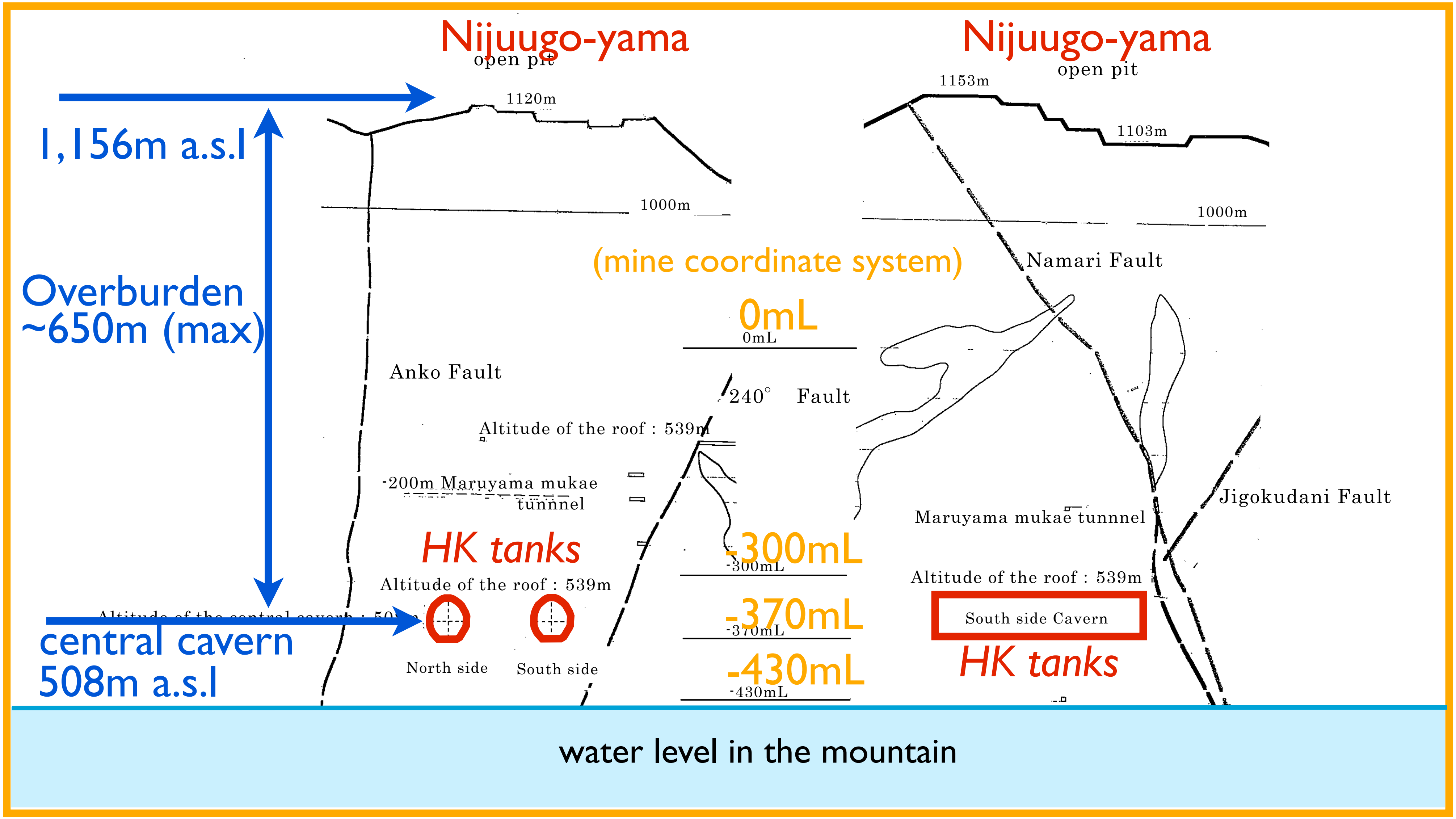
Hyper-K candidate site



- ✦ 8km south from Super-K
  - ✦ same T2K beam off-axis angle (2.5 degree)
  - ✦ same baseline length (295km)
- ✦ 2.6km horizontal drive from entrance



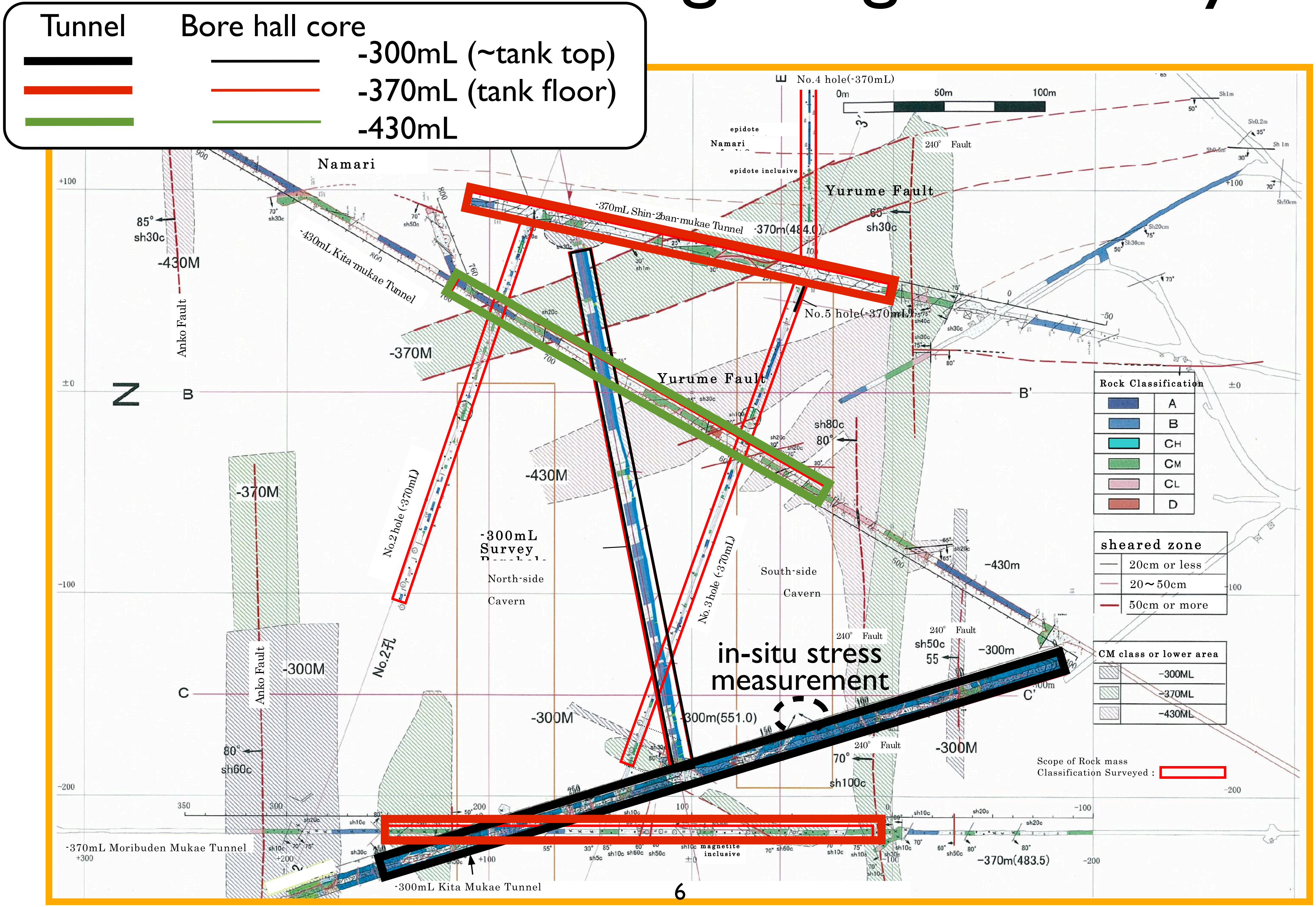
Side view of the site



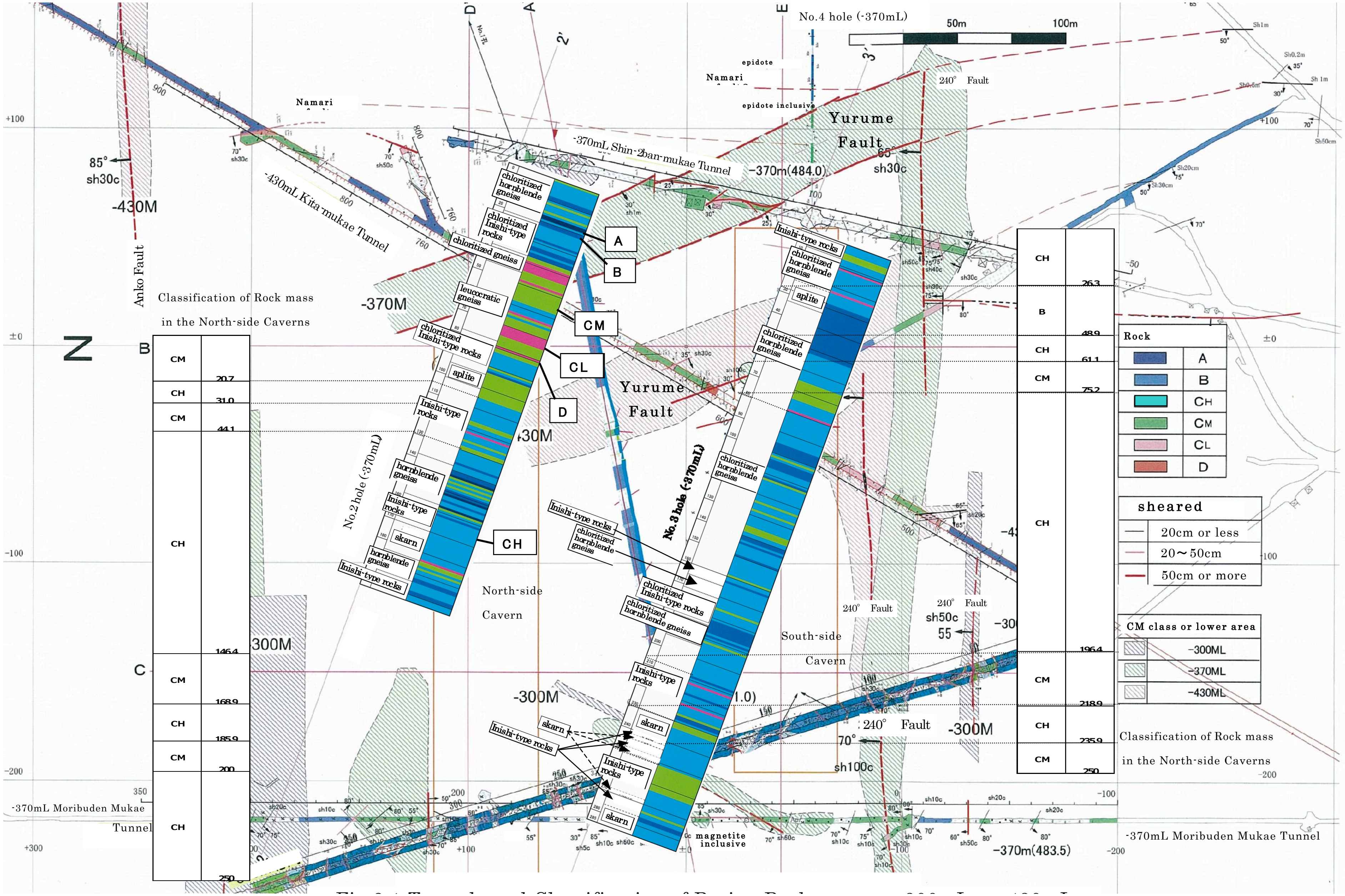
geological survey and rock property measurements

- The candidate site is dominated by gneiss and Inishi-type rock. Contaminated with skarn, aplite, clay.
- Survey in the tunnels and the boreholes were performed
  - Obtain classification of rock mass
- in-situ rock stress measurements were performed at -300mL.
- Borehole loading tests were also performed to estimate the mechanical properties of in-situ rock mass.

Overview of the geological survey



Rock class model (-370mL, tank floor level)



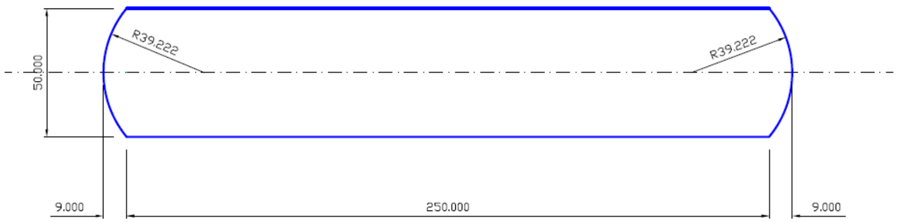
Cavern analysis

	Rock mass class (%)					
	A	B	CH	CM	CL	D
North-side Cavern	0.0	0.0	71.8	28.2	0.0	0.0
	71.8			**28.2**		
South-side Cavern	0.0	9.0	70.7	20.3	0.0	0.0
	79.7			**20.3**		
Total	0.0	4.5	71.3	24.2	0.0	0.0
	75.8			**24.2**		

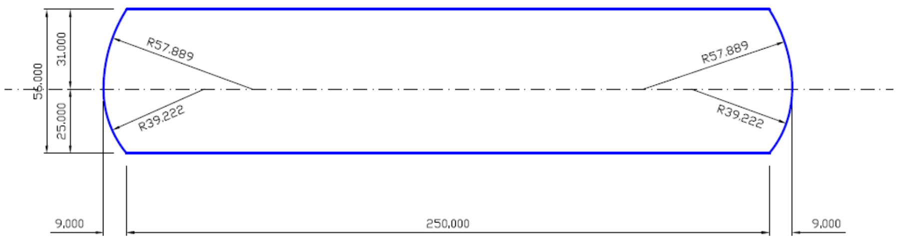
Table 3.4 Input Property Values

Rock mass class	B	CH	CM
Young’ s modulus(kN/mm2)	10.10	3.43	1.22
Poisson’ s ratio	0.25	0.25	0.25
Cohesion(N/mm2)	4.90	2.40	1.40
Internal friction angle(deg)	60.00	50.00	45.00

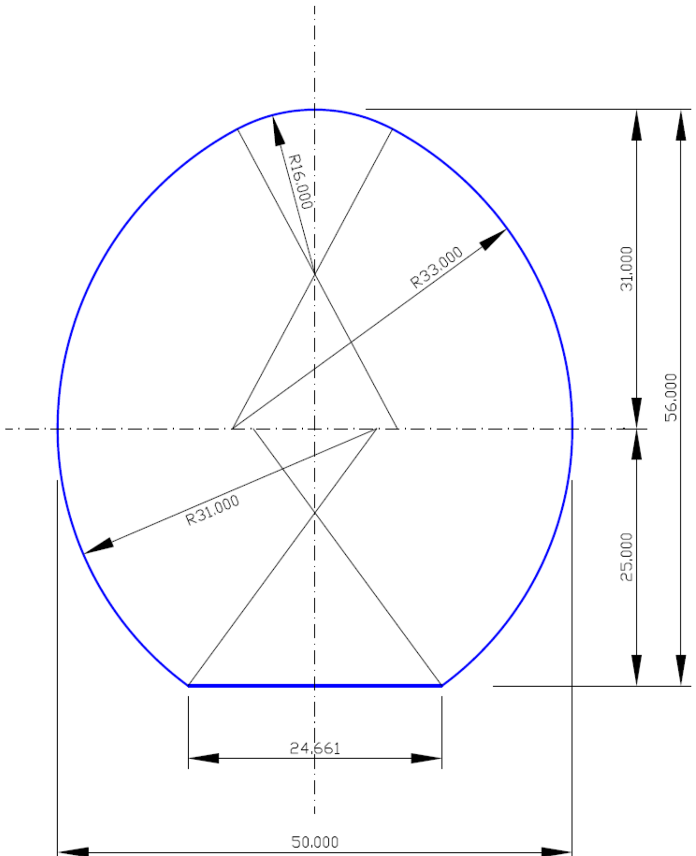
Plane View



Longitudinal Sectional View



Cross-Section View



Results of cavern analysis

B class | CH class | CM class

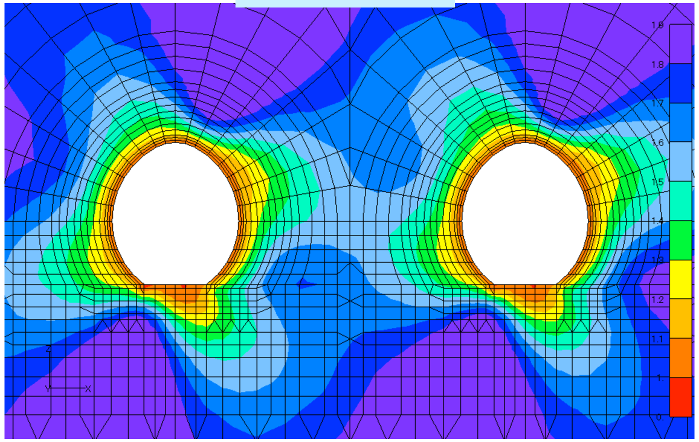


Fig.3.11 (a)-1 Distribution of Local Safety Factor (B class : Cross-section)

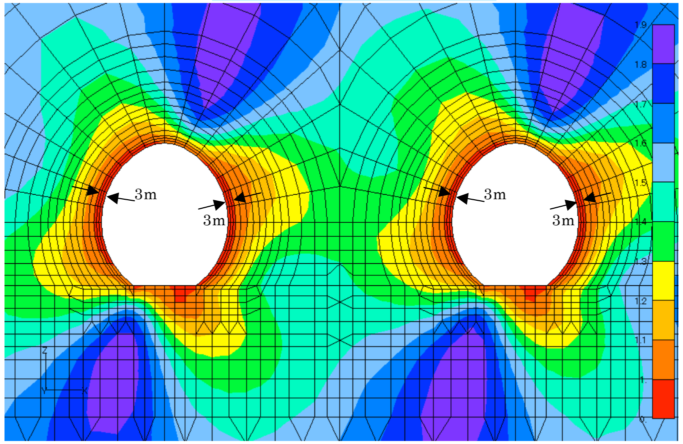


Fig.3.11 (b)-1 Distribution of Local Safety Factor (CH class : Cross-section)

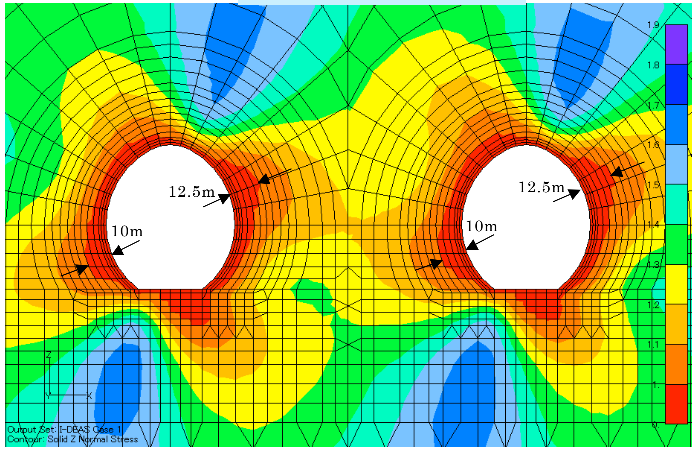


Fig.3.11 (c)-1 Distribution of Local Safety Factor (CM class : Cross-section)

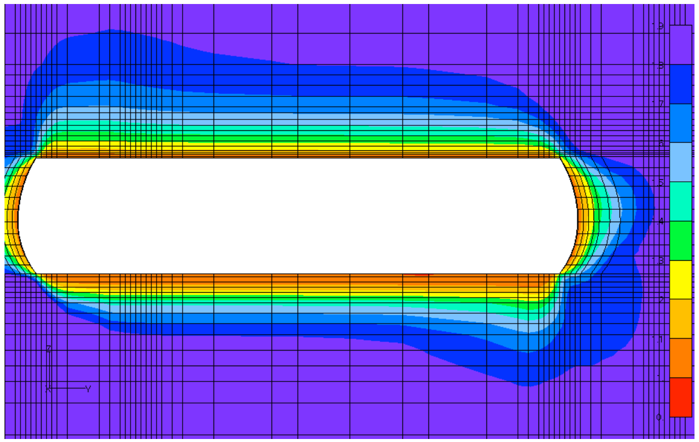


Fig.3.11 (a)-2 Distribution of Local Safety Factor (B class : Longitudinal section)

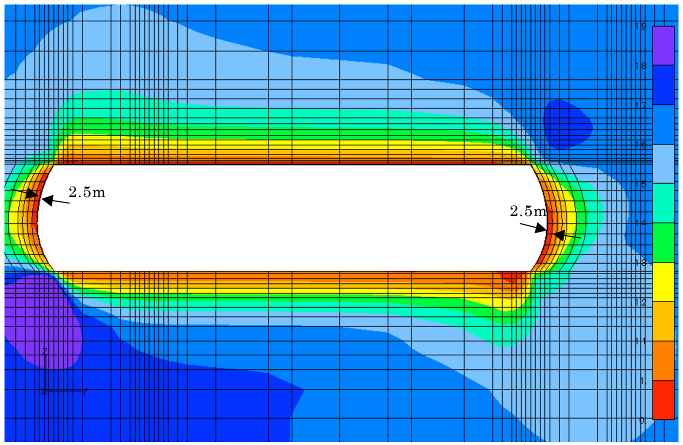


Fig.3.11 (b)-2 Distribution of Local Safety Factor (CH class : Longitudinal section)

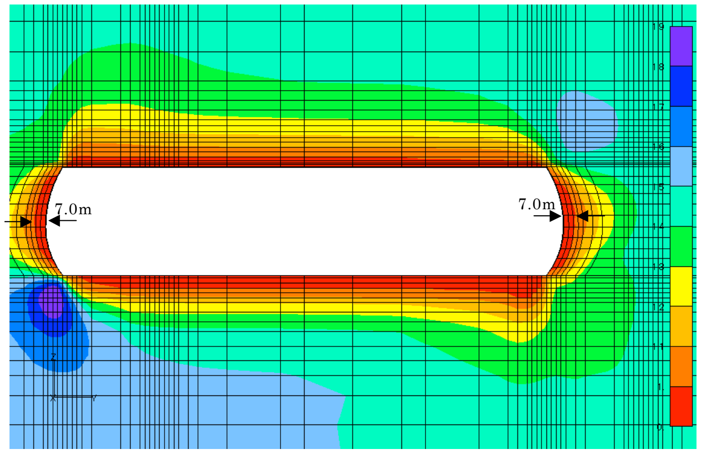
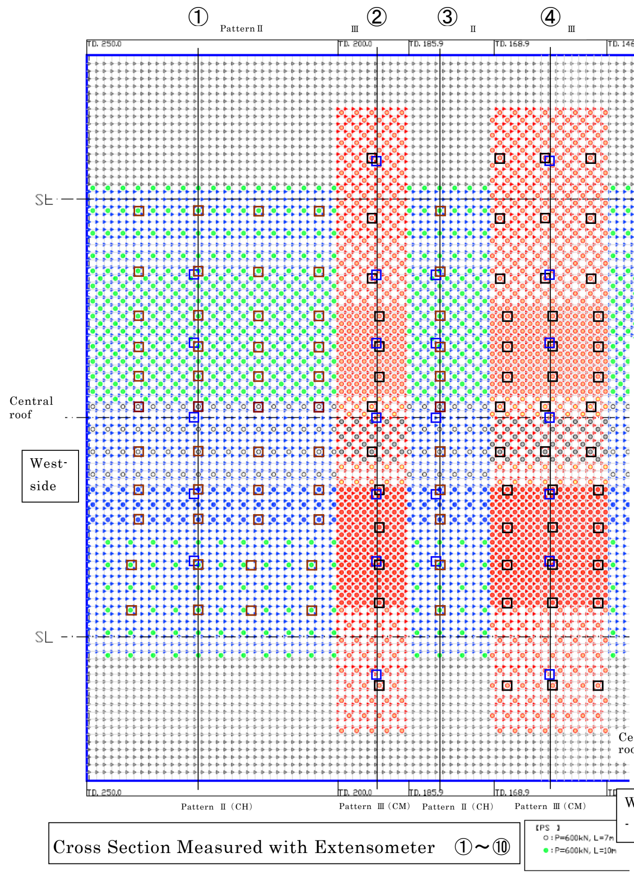


Fig.3.11 (c)-2 Distribution of Local Safety Factor (CM class : Longitudinal section)

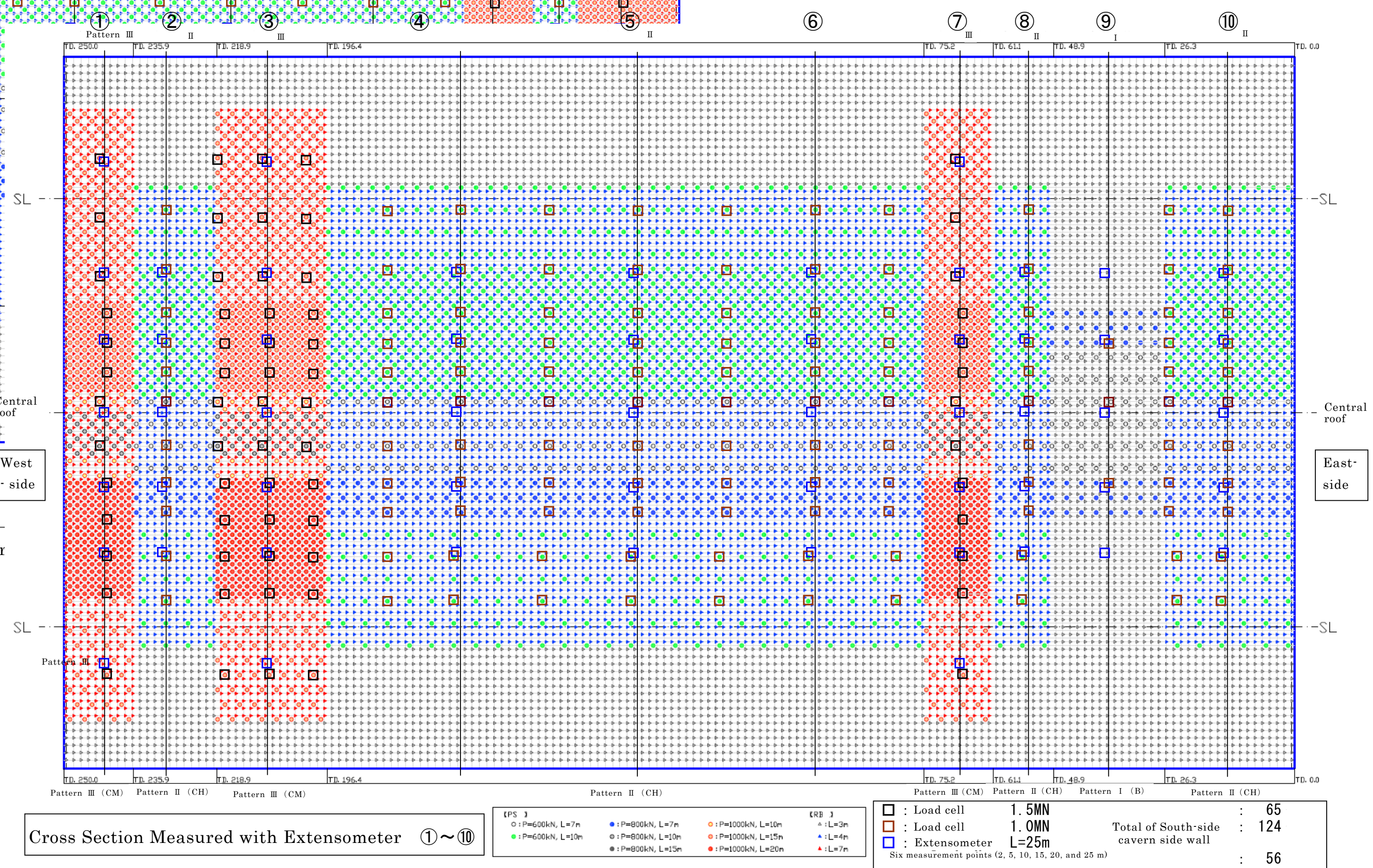
- ~12m depth of loosened region is affordable by appropriate design of PS anchors and rock bolts.
- Past experiences in underground power plants in Japan.

anchors and cable-bolts



Cross Section Measured with Extensometer ①～⑩

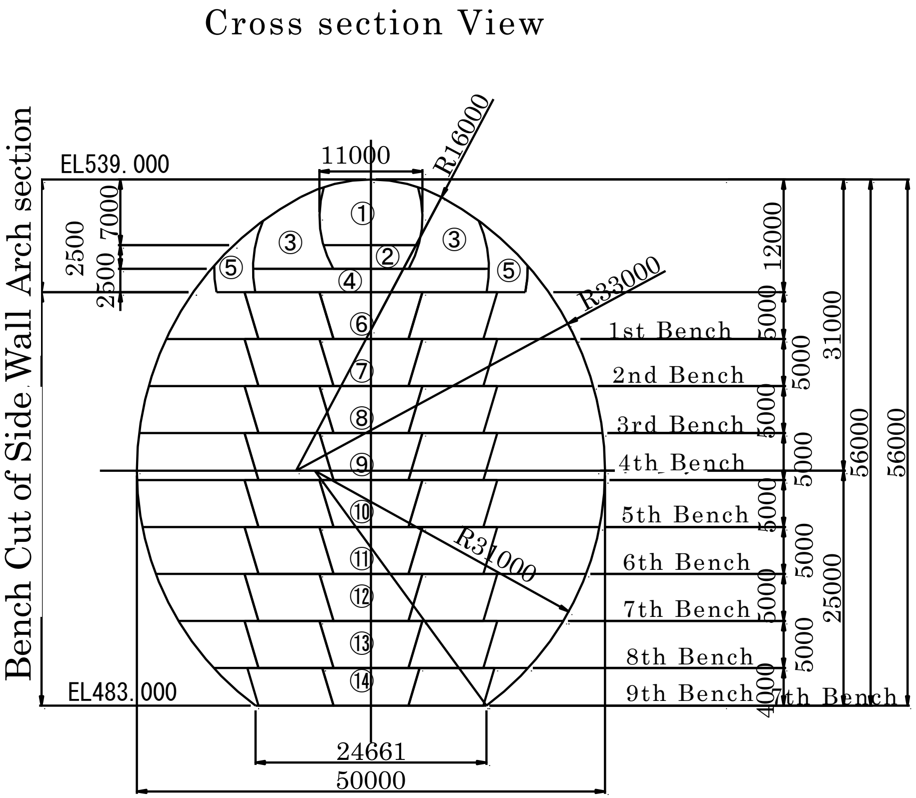
Fig.4.2 (a): Support Pattern of Side Wall on the Nor

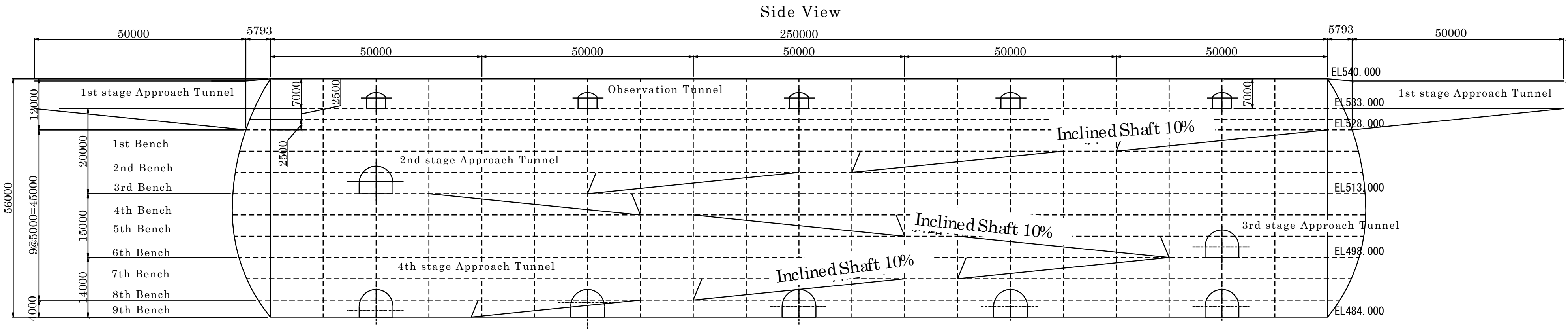


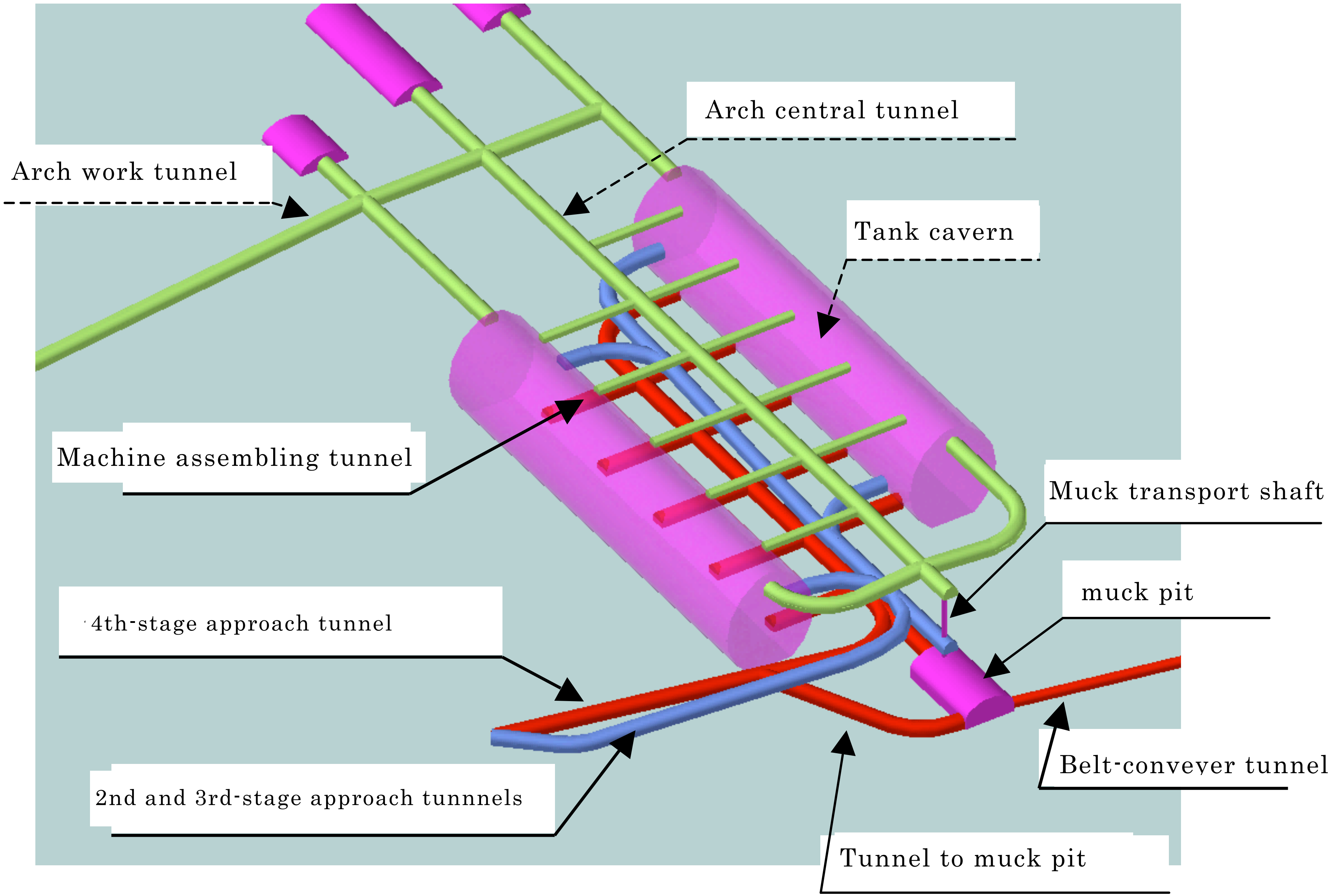
Cross Section Measured with Extensometer ①～⑩

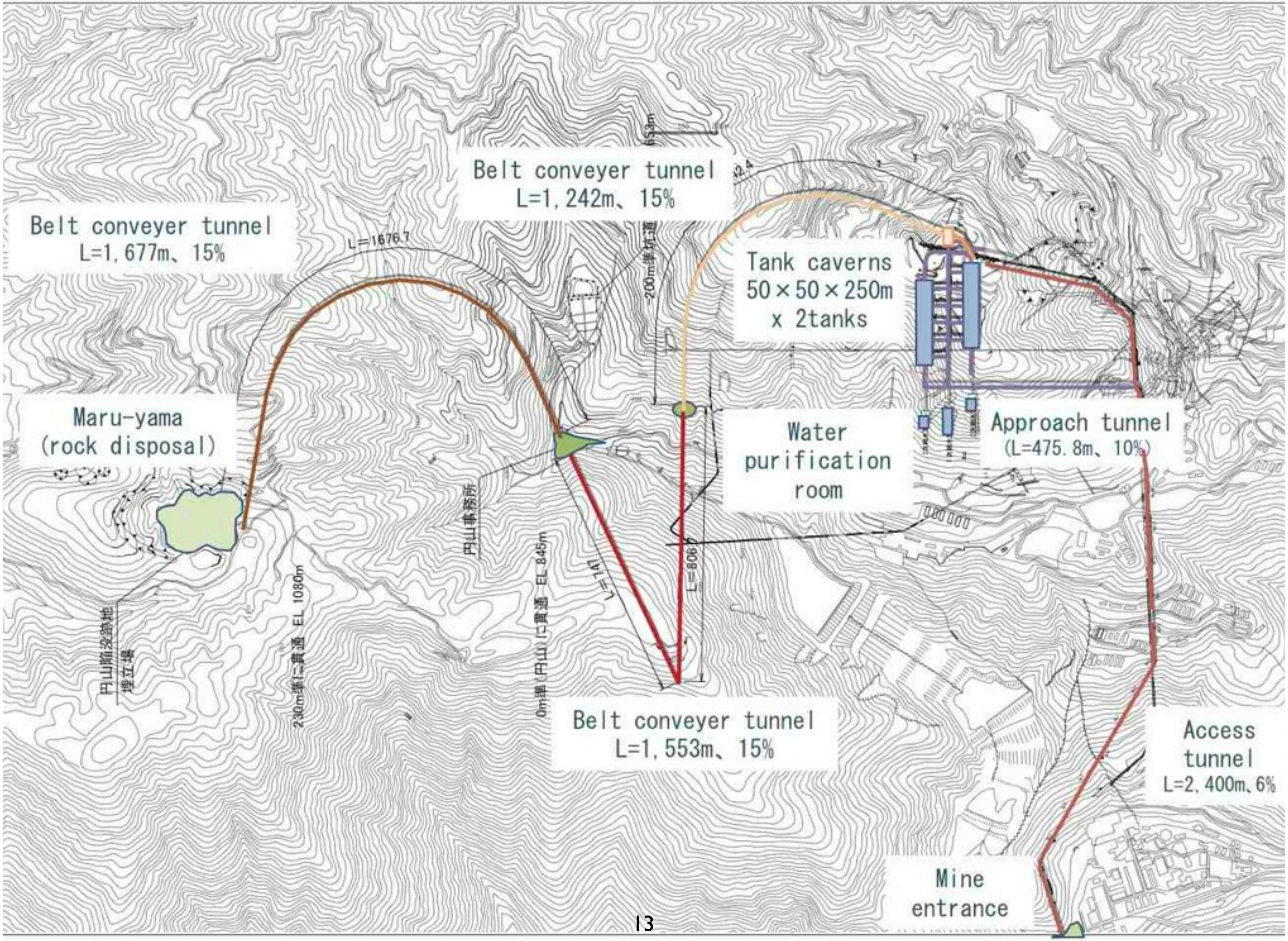
Fig. 4.2 (b) : Support Pattern of Side Wall on the South Side Tank Cavern and Layout of Measurement Equipment Items Applied

Excavation (bench cut)



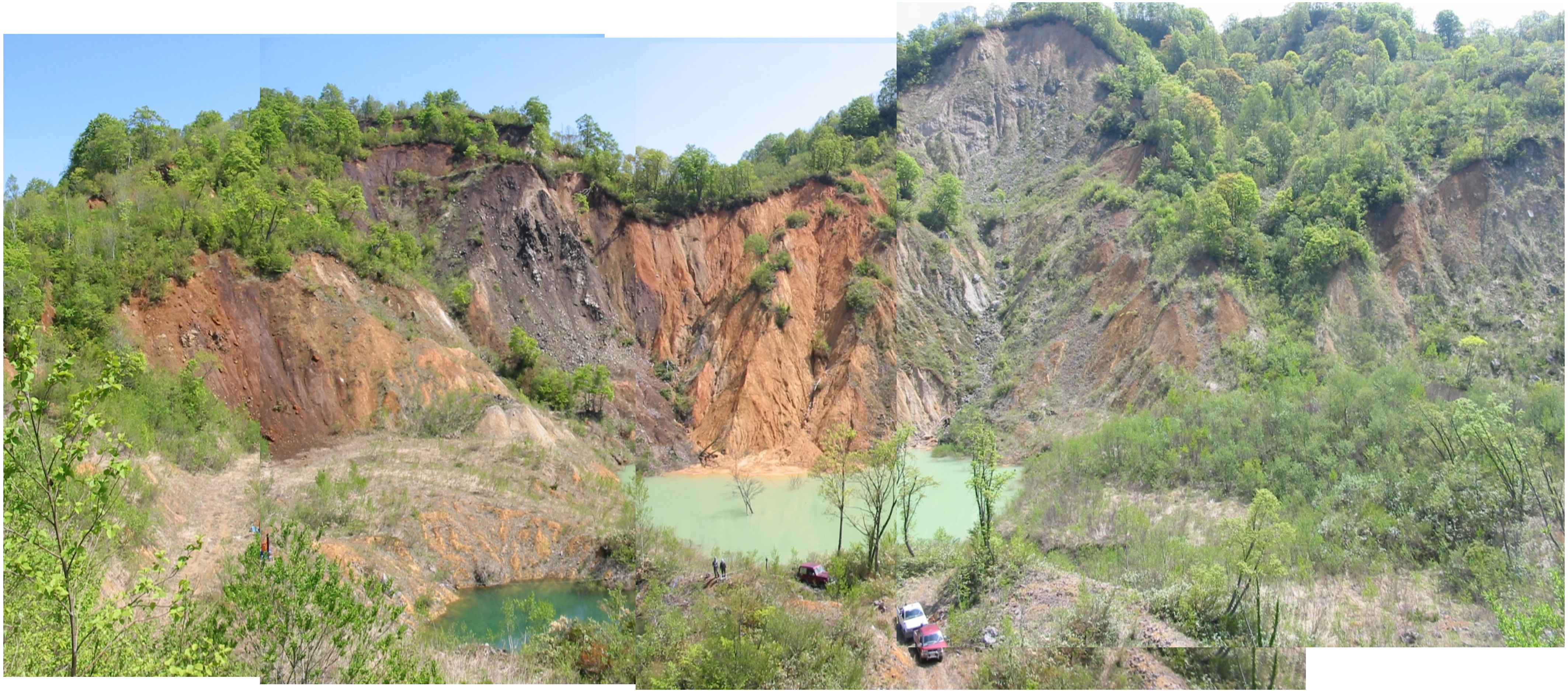



Arch central tunnel
Arch work tunnel
Tank cavern
Machine assembling tunnel
Muck transport shaft
muck pit
4th-stage approach tunnel
Belt-convever tunnel
2nd and 3rd-stage approach tunnnels
Tunnel to muck pit



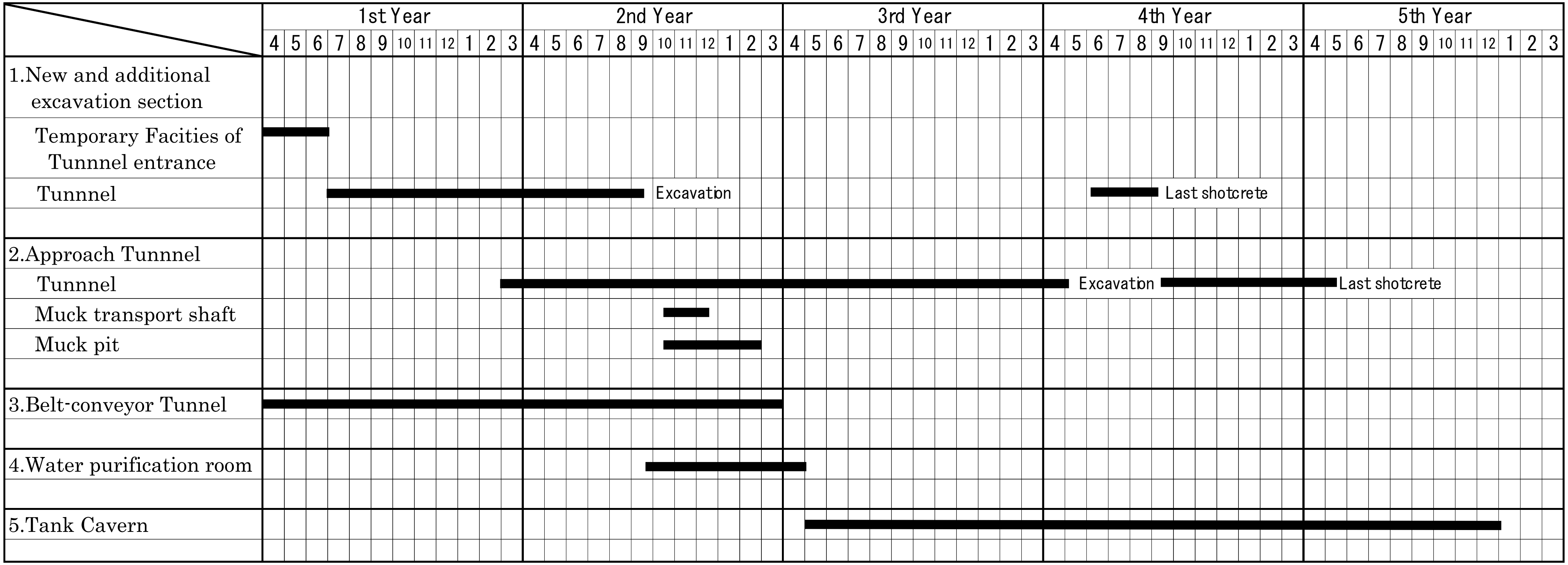
Belt conveyer tunnel
L=1,677m、15%
L=1676.7
Belt conveyer tunnel
L=1,242m、15%
Tank caverns
50×50×250m
x 2tanks
Maru-yama
(rock disposal)
Water
purification
room
Approach tunnel
(L=475.8m、10%)
L=806
Belt conveyer tunnel
L=1,553m、15%
Access
tunnel
L=2,400m、6%
Mine
entrance

Waste rock disposal place



- need to secure the disposal place, for example, geological survey, stability study are yet to be done.

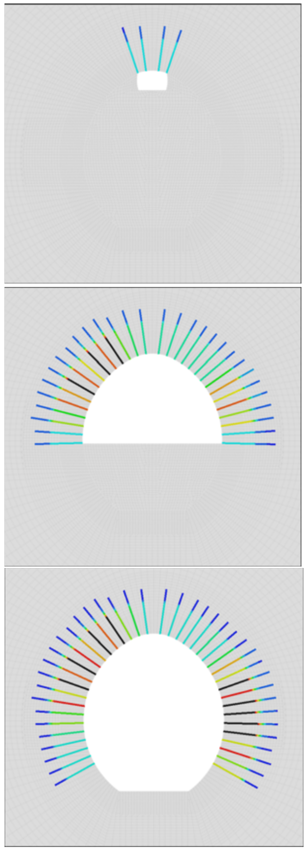
Table 6.1 Construction outline schedule chart of HK-Project



~5 years for excavation

More accurate analysis (ongoing study)

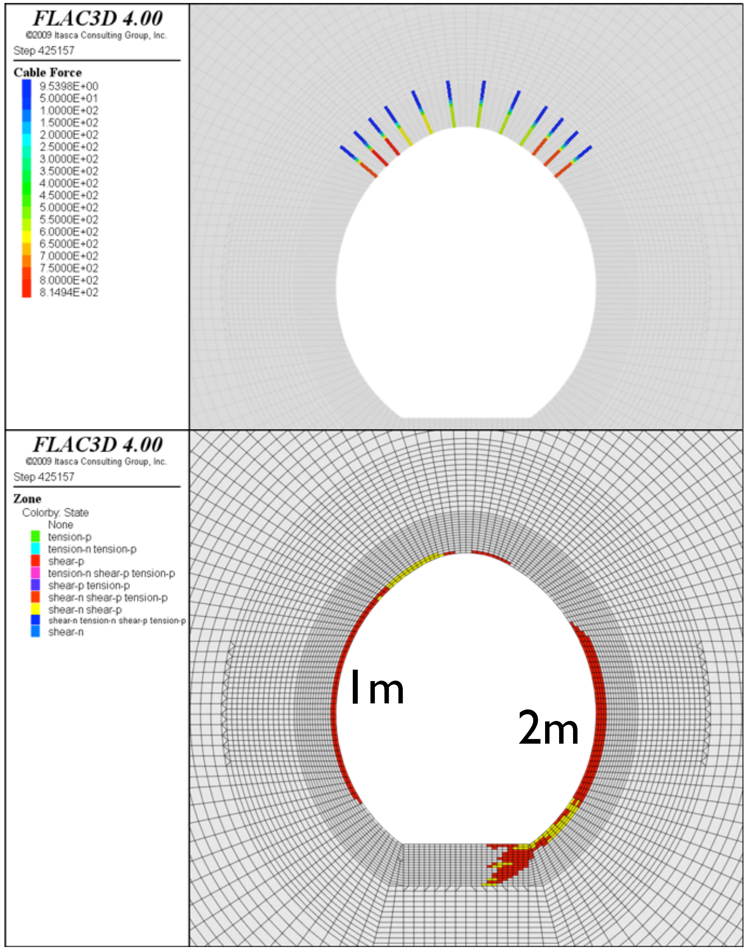
- Elastic, static analysis was conduced
  - one calculation for the whole cavern.
  - evaluate the plasticity region based on elastic analysis
    - Mohr-Coulomb's criterion as failure criteria, general (mean) values for Young's modulus
    - design PS anchors, rockbolts, and shotcrete to support the loosened area.
    - elastic limit of the supports themselves not taken into account



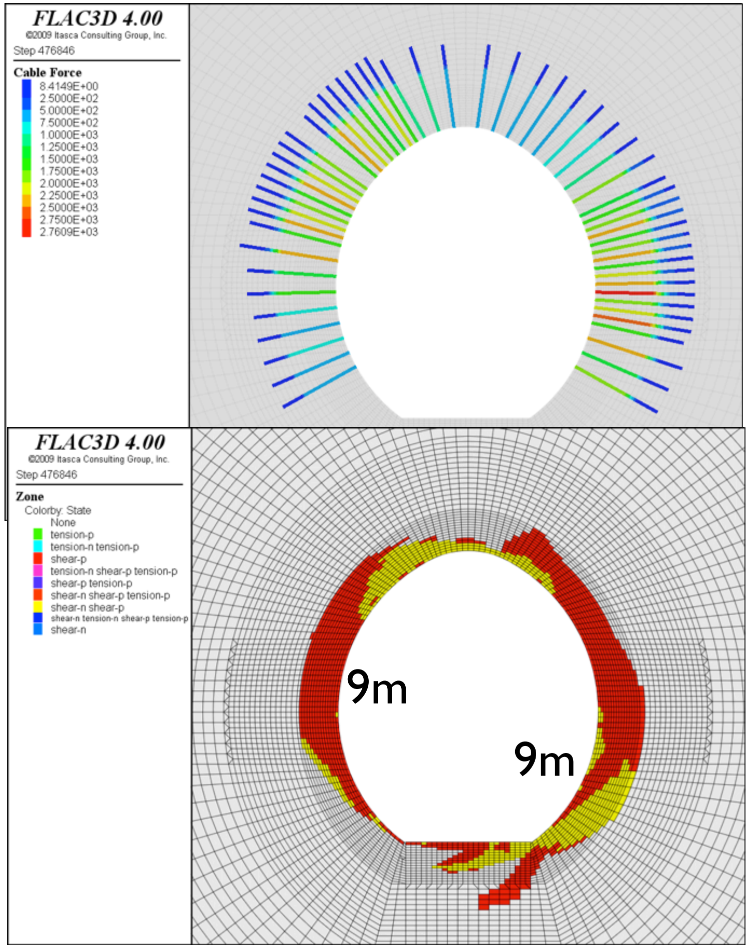
- Elasto-plastic, static analysis (ongoing study)
  - step-by-step calculations for each excavation benches.
  - perform calculation even after the stress exceeds the elastic limit.
    - Hoek-Brown's criterion as failure criteria, revised Young's modulus
    - strain softening calculation
    - Designed supports are considered in the calculation
    - elastic limit of the supports also taken into account.

Preliminary results

B class



CH class



affordable cable tension and plasticity region depth for B and CH class.

Remarks on the cavity analysis

- Analysis for CM class contamination yet to be done.
  - Results should depend on size and position of the CM area.
- The cavern construction is feasible but final tuning of the shape and size might be necessary when pre-construction survey is conducted.

- Estimation of cost and construction period to be revised near future.

supplements

Table 2.1 Rock mass classification of Central Research Institute of Electric Power Industry

Fresh, Solid

Degraded

Rock class	Description
A	The rock mass is very fresh, and the rock forming minerals and grains undergo neither weathering nor alteration. Joints are extremely tight and their surfaces ha no visible sign of weathering. Sound by hammer blow is clear.
B	The rock mass is solid. There is no opening joint and crack (even of 1 mm). But rock forming minerals and grains undergo a little weathering and alteration in partly. Sound by hammer blow is clear.
CH	The rock mass is relatively solid. The rock forming minerals and grains undergo weathering except for quartz. Rock is contaminated by limonite, etc. The cohesion of joints and cracks are slightly decreased. Clay minerals remain on the separation surface. Sound by hammer blow is a little dim.
CM	The rock mass is somewhat soft. The rock forming minerals and grains are somewhat softened by weathering, except for quartz. The cohesion of joints and cracks is somewhat decreased and rock blocks are separated by ordinary hammer blow along the joints. Clay materials remain on the separation surface. Sound by hammer blow is somewhat dim.
CL	The rock mass is soft. The rock forming minerals and grains are softened by weathering. The cohesion of joints and cracks is decreased and rock blocks are separated by soft hammer blow along the joints. Clay minerals remain on the separation surface. Sound by hammer blow is dim.
D	The rock mass is remarkably soft. The rock forming minerals and grains are softened by weathering. The cohesion of joints and cracks is almost absent. The rock mass collapses by light hammer blow. Clay minerals remain on the separation surface. Sound by hammer blow is remarkably dim.

Note: CRIEPI: Central Research Institute of Electric Power Industry

Referencs : R.Yoshinaka, S.Sakurai, K.Kikuchi : 岩盤分類とその適用, Journal of the Japan

Summary of rock classification

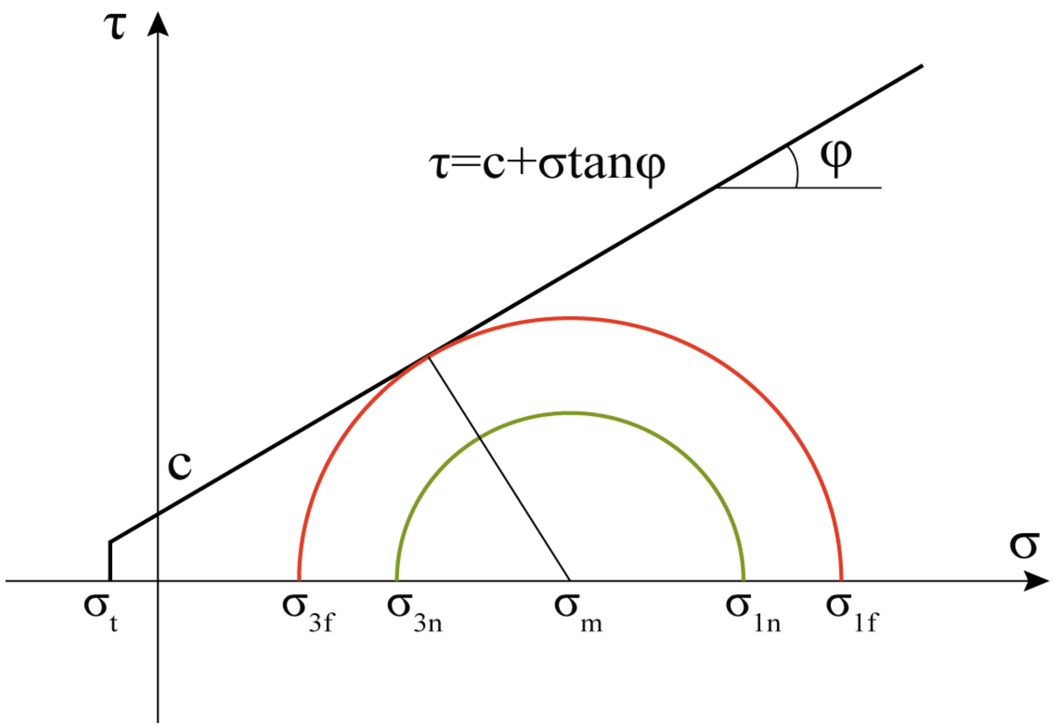
Table 2.3: Classification of Rock mass in the Tunnels

	Rock mass class (%)					
	A	B	CH	CM	CL	D
-300mL Kita-mukae Tunnel	0.0	51.6	43.6	3.0	1.8	0.0
	95.2			**4.8**		
-300mL Survey Borehole	0.0	67.9	27.7	4.0	0.4	0.0
	95.6			**4.4**		
-370mL Moribuden-mukae Tunnel	0.0	11.4	45.4	39.8	3.4	0.0
	56.8			**43.2**		
-370mL Shin-2ban-mukae	0.0	4.9	55.7	25.0	14.4	0.0
	60.6			**39.4**		
-370mL Survey Borehole No.2	2.4	10.5	49.2	29.7	5.7	0.2
	62.1			**35.6**		
-370mL Survey Borehole No.3	0.0	19.2	59.2	16.5	3.8	0.3
	78.4			**20.6**		
-370mL Survey Borehole No.4	6.6	20.5	36.4	22.6	7.1	3.1
	63.5			**32.8**		
-430mL Kita-mukae Tunnel	0.0	18.1	39.0	38.1	1.9	2.9
	57.1			**42.9**		

- Suggesting that the area at 300mL and above has fairly good rock conditions.
- No data below -430mL

Factor of safety

- Using the Mohr-Coulomb criterion, the local factor of safety is calculated and compared a series of 3D stress analyses by FLAC3D.



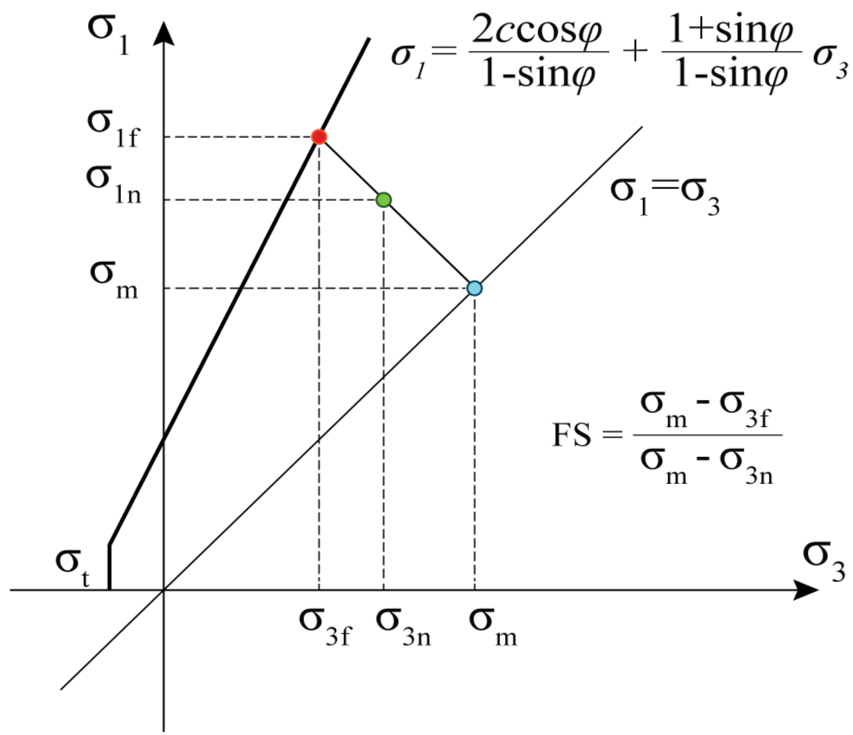
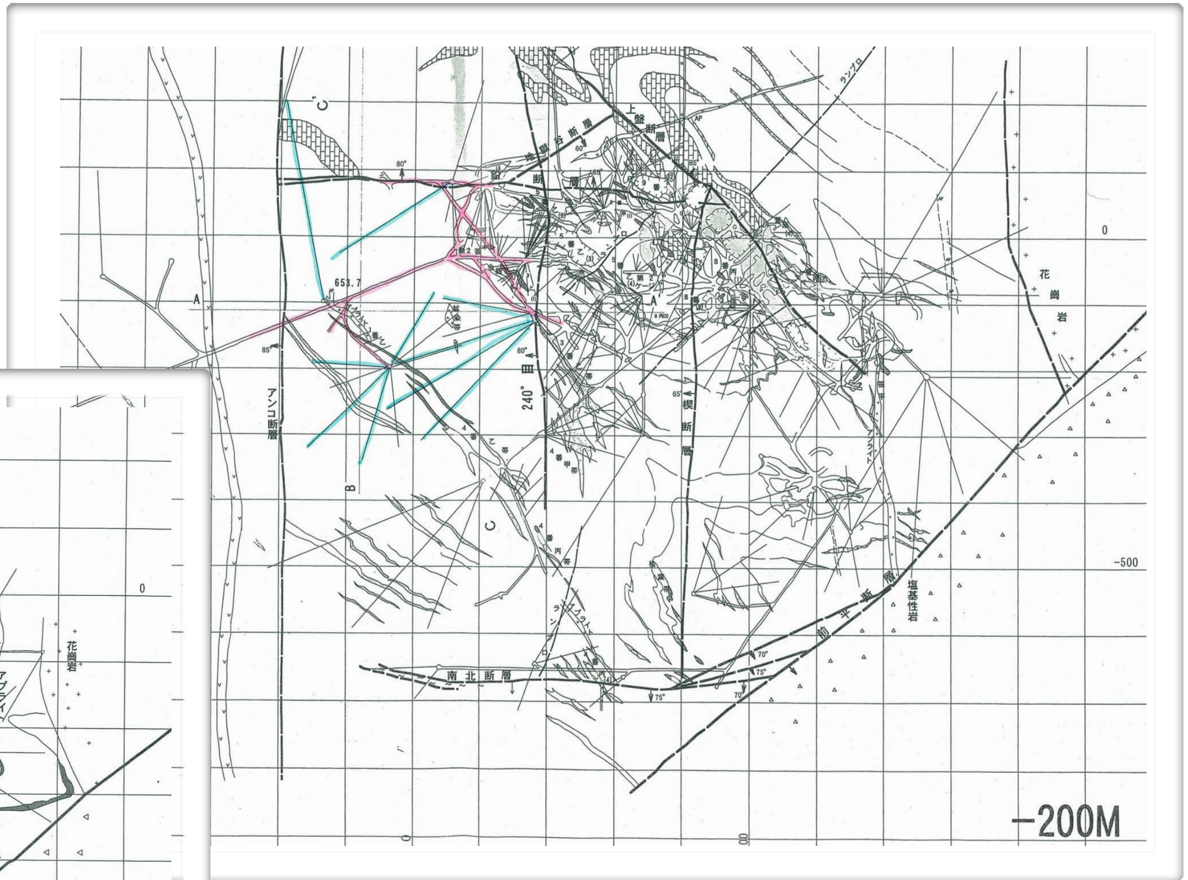
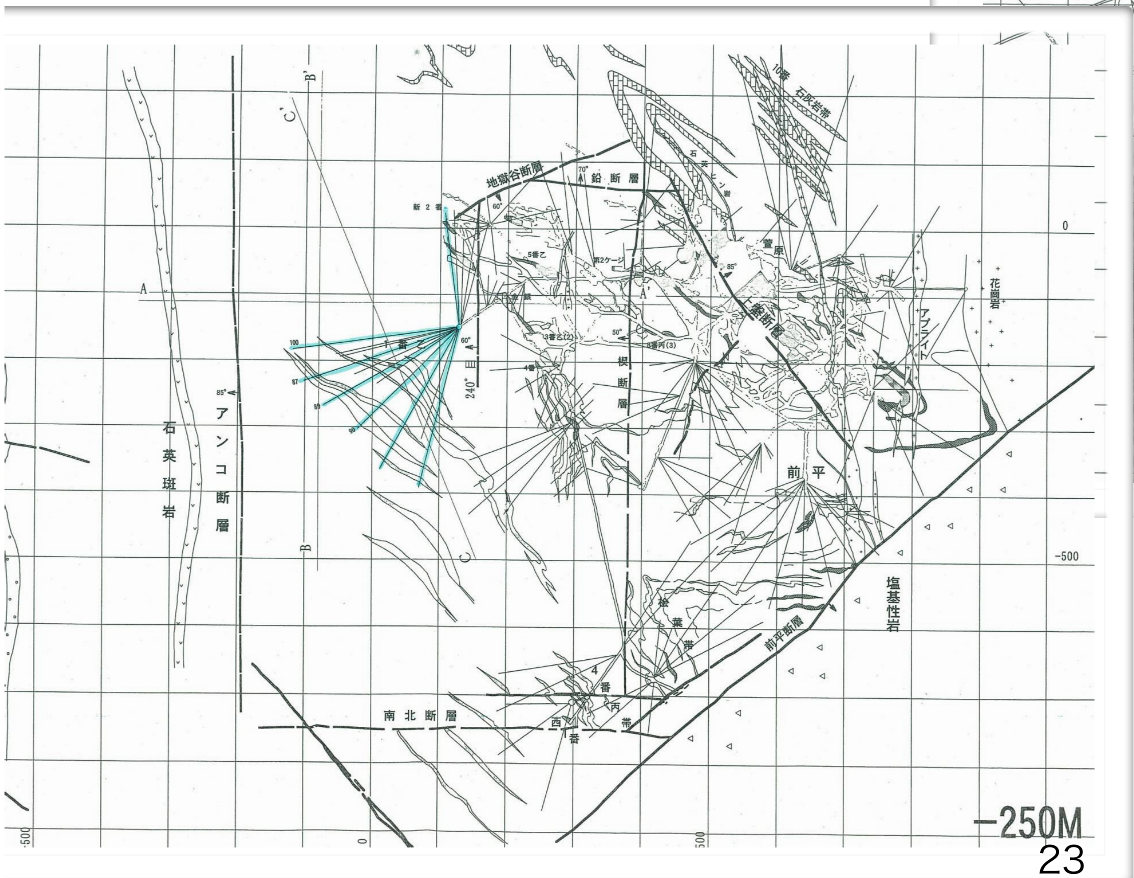


Fig. Factor of safety(Strength/stress ratio) for Mohr-Coulomb failure criterion. (Left : relation of normal and shear stresses, Right : relation of major and minor principal stresses)

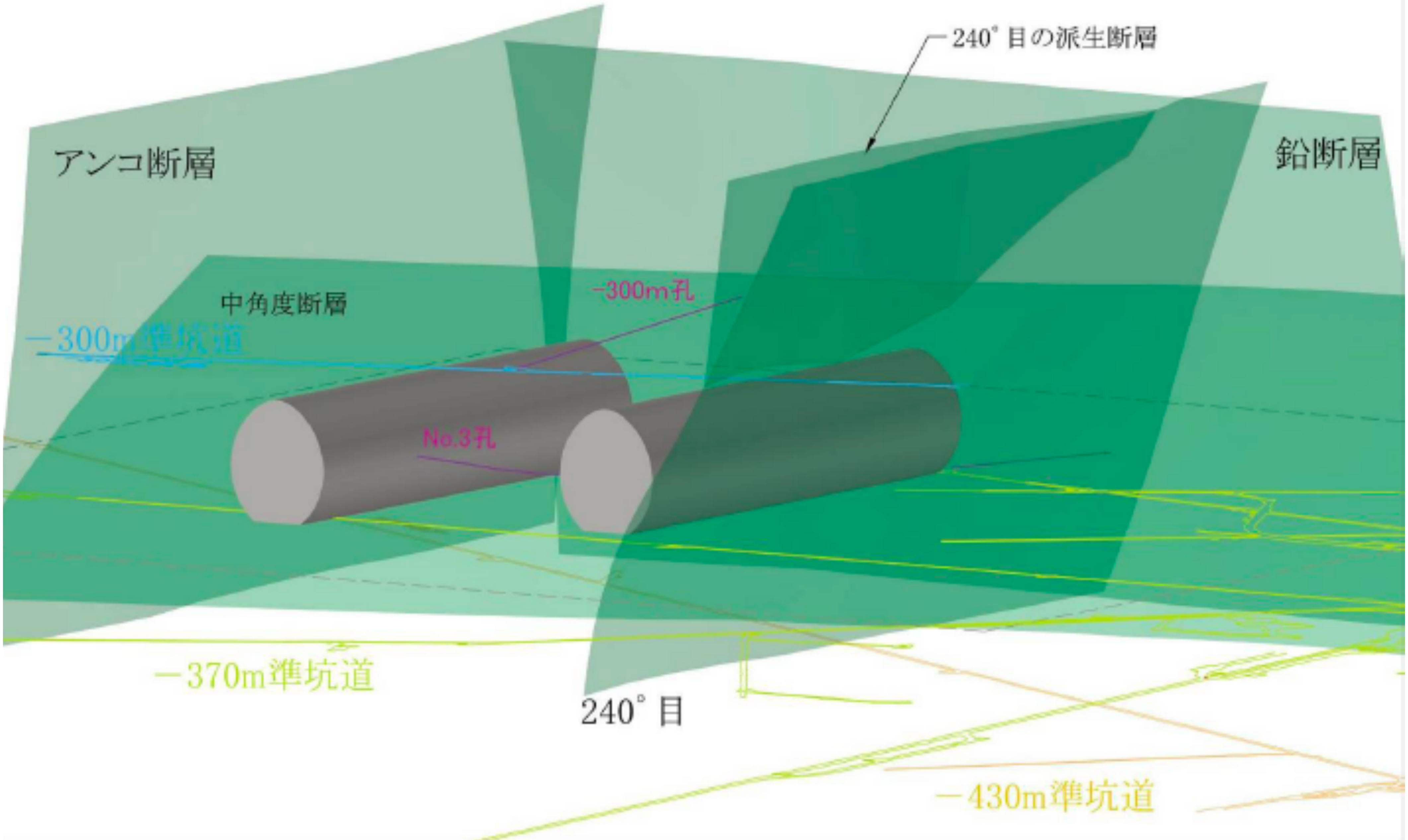
- The strength for the stress state represented by green circle is determined by holding mean stress(σ_m) while increasing or decreasing normal stresses(σ_1 ,σ_3) until red circle touches the envelope. The ratio of the radii of the two circles is the factor of safety.

collecting rock quality data for shallower levels.





＜主要断層　西北西からの鳥瞰＞



茂住鉱岩盤調査

- 調査坑道の岩盤は比較的堅硬であり、L級以下の岩盤は出現しない。
- 調査坑道の周辺坑道では断層・亀裂があり、M・L級の岩盤が多い。
- ボーリングNo.1孔の岩盤は調査坑道とほぼ同様の比較的堅硬な岩盤状況であるが深度60m以深ではL級の岩盤が出現する。
- ボーリングNo.2孔では深度50m付近までは調査坑道と同様であるが、50m以深ではM・L級を主体とした岩盤となる。
- 調査坑道入口では13号ヒ断層を確認した。