Site Selection, Safety Review, Safety Confirmation, and Monitoring

7. Foundation and Slope Stability

(SER 2.5.4 & 2.5.5)

Taek-Mo SHIM

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Korea Institute of Nuclear Safety

Structural Systems and Site Evaluation Department

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Basic Information

Design considerations of Foundation

Engineering properties of rocks

Foundation stability evaluation

Slope stability evaluation

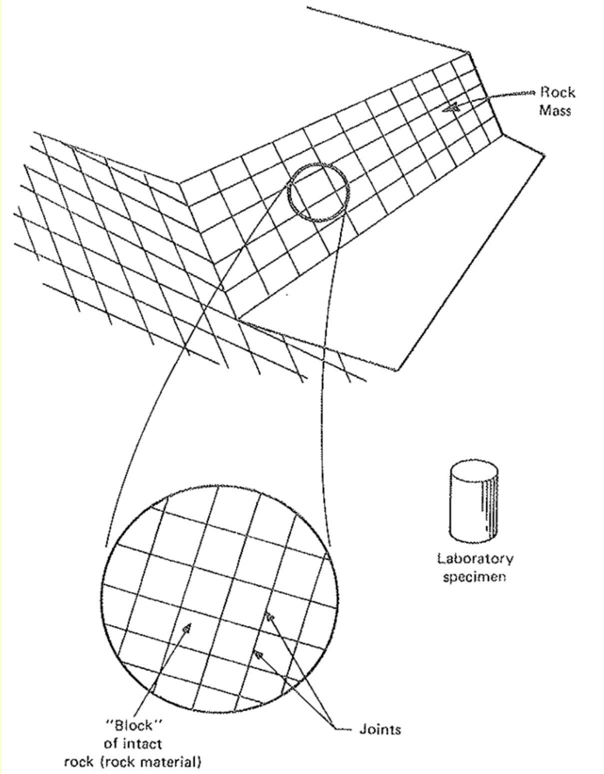
Basic Information

- Basic considerations
  - Foundation stability evaluation methods, investigation or test methods are dependent on the site condition (rock site or soil site)
  - Full understanding of geological characteristics is necessary before selecting the evaluation and test methods
  - The range of application and restrictions of test methods are considered

- Understanding of representative value
  - Not one method of test results are utilized for the determination of the property value
  - Results from more than two test methods are utilized
  - Special attention be given the No. of test(samples) and its standard deviation

Basic Information

- Rock and rock mass discrimination
  - Rock (material)
    - Intact rock with no joint
    - Used for Rock classification and characterization
  - Rock mass
    - Whole rock with joint, it represents the real condition of foundation materials
    - Large-scale rock mass behavior must be considered in all real rock engineering problem
    - Lab. Test on the specimen is only one step for understanding of in-situ rock performance



Contents

Design considerations of foundation

- Stable condition of foundation
  - Stable geologic condition with homogeneous subsurface materials
  - Suitable bearing capacity with limited (differential) settlement
- Major evaluation items
  - Bearing capacity
  - Settlement or differential settlement
  - Liquefaction potential
  - Seismic wave propagation characteristics
  - Slope stability
  - Possibility of improvement of weak foundation materials

Design considerations of foundation

- Basic data necessary to evaluate the foundation stability
  - Geological characteristics and geological structure
  - Static engineering properties
    - Unit weight, poisson's ratio, compressive strength, young's modulus, deformation modulus, etc.
  - Dynamic engineering properties
    - Poisson's ratio, young's modulus, compressional/shear wave velocity, seismic wave velocity profile
  - Ground water condition
    - Groundwater level, water quality, existence of artesian condition, etc
  - Layout of the facilities and the nature of the structural foundation
  - Characteristics of permanent or temporal cut slope

Contents

- Basic Information
- Design considerations of Foundation
- **Engineering properties of rocks**
- Foundation stability evaluation
- Slope stability evaluation

Engineering properties of rocks

Representative geotechnical investigations and tests

- Surface geologic investigation
- Boring (borehole logging)
- Trenches
- Geophysical exploration (seismic wave velocity and velocity structure)
- Groundwater exploration
- In-situ test (rock mass deformation test, Point Load Test, Standard Penetration Test, etc.)
- Laboratory test (index test, compressive strength, sonic velocity, etc.)

Engineering properties of rocks

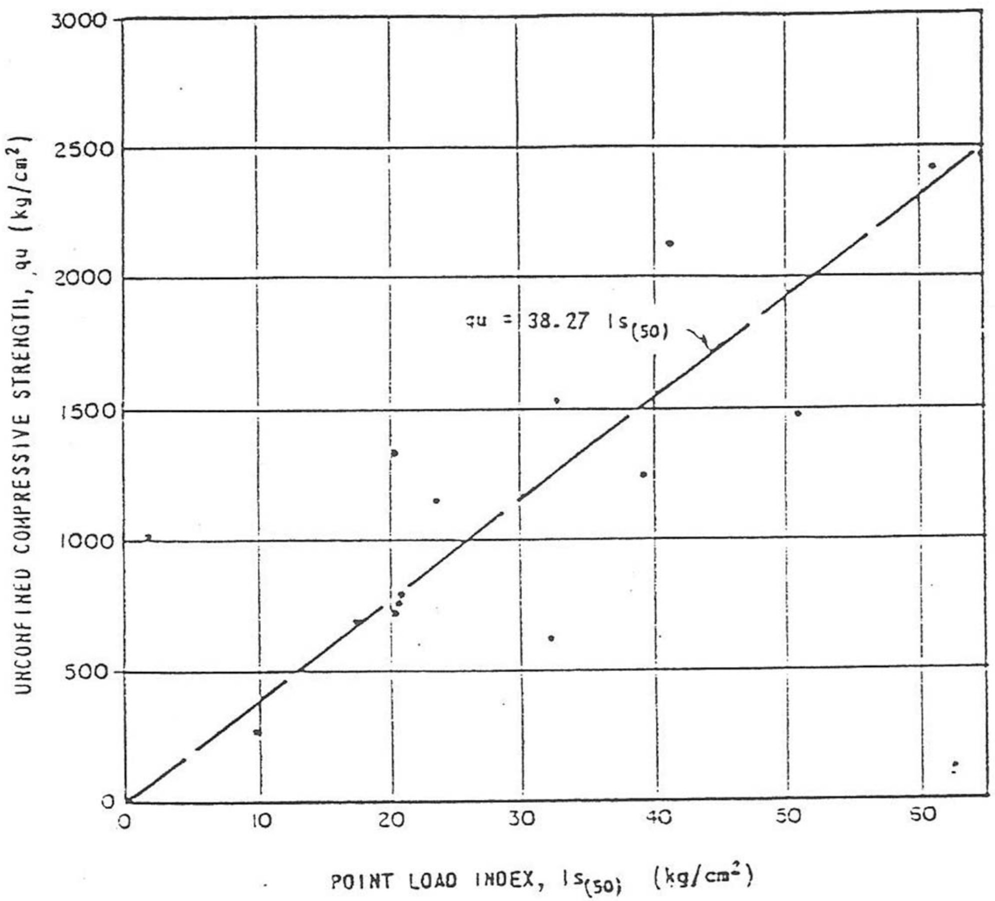
- Uniaxial compressive strength(Qu)
  - Using for the the determination of **bearing capacity** of foundation material
  - Triaxial/Uniaxial compressive strength test
  - **Uniaxial compressive strength test**
    - $Qu = P/A = 4P/\pi D^2$ D:Diameter of core, P:stress acting parallel to axis of core,
      A: cross section of the core
  - Point load test (**PLT**) : in-situ test for obtaining point load index
    - $Is = P/d^2$, $Qu = 24\ I_{s(50)}$ P:failure pressure, **$I_{s(50)}$:point load index**
    - Correction :test results are corrected at D=50mm
    - $Is_{(50)}$=F* Is(F: correction factor,$(D/50)_{0.45}$, Is : Point index by direct measurement)
    - In general, **$Qu = 24 * Is_{(50)}$**(about 20-25 times) is applied

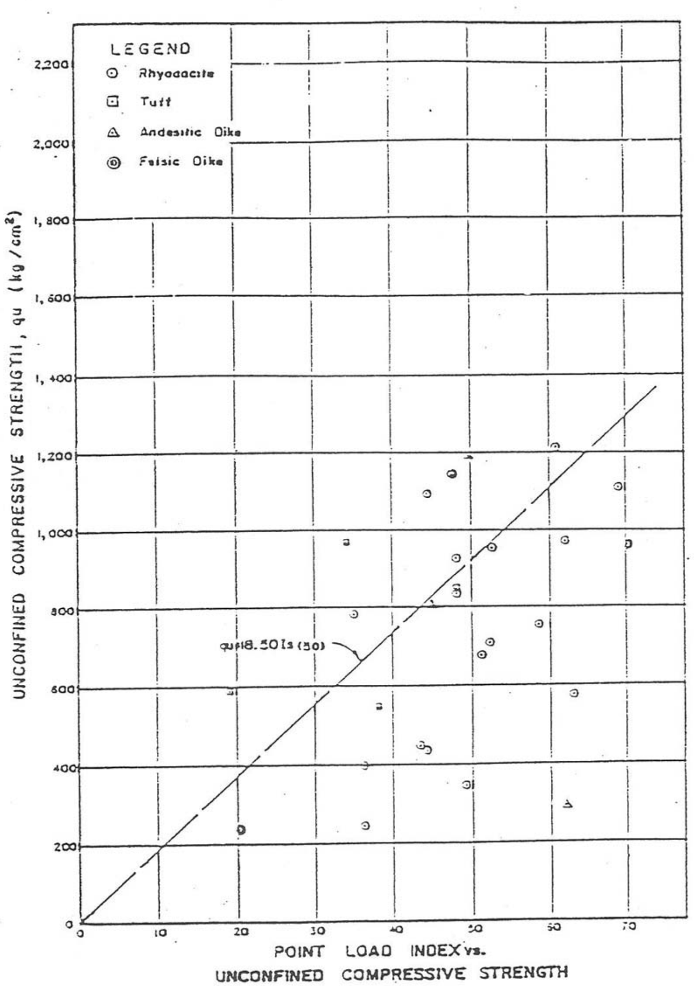
ANSN Asian Nuclear Safety Network

IAEA International Atomic Energy Agency Atoms for Peace

Engineering properties of rocks

- Example of uniaxial compressive strength(Qu) determination using point load index





Engineering properties of rocks

- Selection of representative value (R.V.)
  - **Direct** measurement : in-situ test (rock mass deformation test, joint characteristics, groundwater level, etc.)
  - **Indirect** measurement : correlation with related parameters (Rock Mass Rating, Rock Quality Designation, velocity index, etc.)
  - Selection of R.V. : Consideration of test reliability and site condition

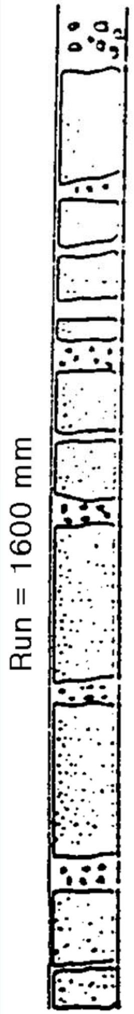
- Rock mass deformation modulus, (Ed)
  - Used for evaluation of deformation characteristics and **settlement** for foundation materials
  - Direct measurement – using the stress-strain relationship
  - Indirect measurement – correlation with related parameters

Engineering properties of rocks

- Rock mass deformation modulus, (Ed)
  - Direct measurement
    - **Jack test**, **elastometer test**, etc
  - Indirect measurement
    - Correlation with **RMR** (Rock mass rating), **RQD** (Rock Quality Designation) and **Velocity index**
    - RMR method : Rating according to compressive strength, RQD, Spacing of joint, nature of joint (surface roughness, fillings, and aperture), joint orientation, and groundwater condition
      - ✓ Correction according to joint geometry
      - ✓ Determination of rock mass deformation modulus using the relationship of the modulus and RMR (Bieniawski, 1978)

Engineering properties of rocks

Definition of **core recovery** and **RQD**



Recovery: Core (all)	Recovery: Modif. core (100 + mm)
25	
132	132
10	
139	139
135	135
18	
23	
120	120
116	116
22	
232	232
14	
222	222
18	
112	112
46	
Σ =1384	Σ =1208

$$\% \text{ Recovery} = \frac{1384}{1600} \times 100 = 86.5\%$$

$$\text{RQD} = \frac{1208}{1600} \times 100 = 75.5\%$$

Rock quality = "fair"

Rock quality[a]	RQD, %
Very poor	0 – 25
Poor	25 – 50
Fair	50 – 75
Good	75 – 90
Excellent	90 –

[a] From Deere (1968)

Compressive strength (MPa)	Rating
> 250	15
100-250	12
50-100	7
25-50	4
10-25	2
2-10	1
1-2	0

- Core recovery is the ratio of recovered core length to total length drilled, expressed as percentage
- RQD is the sum of the length of rock core pieces longer than 10cm. It expressed as a percentage of a given total length drilled

Engineering properties of rocks

RMR Score and Rock Quality by RQD

RQD (%)	Score	Rock Quality
90 ~ 100	20	Excellent
75 ~ 90	17	Good
50 ~ 75	13	Fair
20 ~ 50	8	Poor
＜25	3	Very Poor

RMR Score by Joint Spacing

Joint Spacing (m)	Score
＞2.0	20
0.6 ~ 2.0	15
0.2 ~ 0.6	10
0.06 ~ 0.2	8
＜0.06	5

RMR Score by Joint Condition

Joint Condition	Score
Very rough surface within a limited range; hard rock	30
Slightly rough surface; less than 1 millimeter in joint width; hard rock	25
Slightly rough surface; less than 1 millimeter in joint width; soft rock	20
Smooth surface; gouge-filling substances with the thickness of 1-5 millimeters; joint extended for over several meters	10
Open joint filled with gouge of over 5 millimeters in thickness	0
Open by over 5 millimeters; joint extended for over several meters	0

Engineering properties of rocks

RMR Score by Groundwater Condition

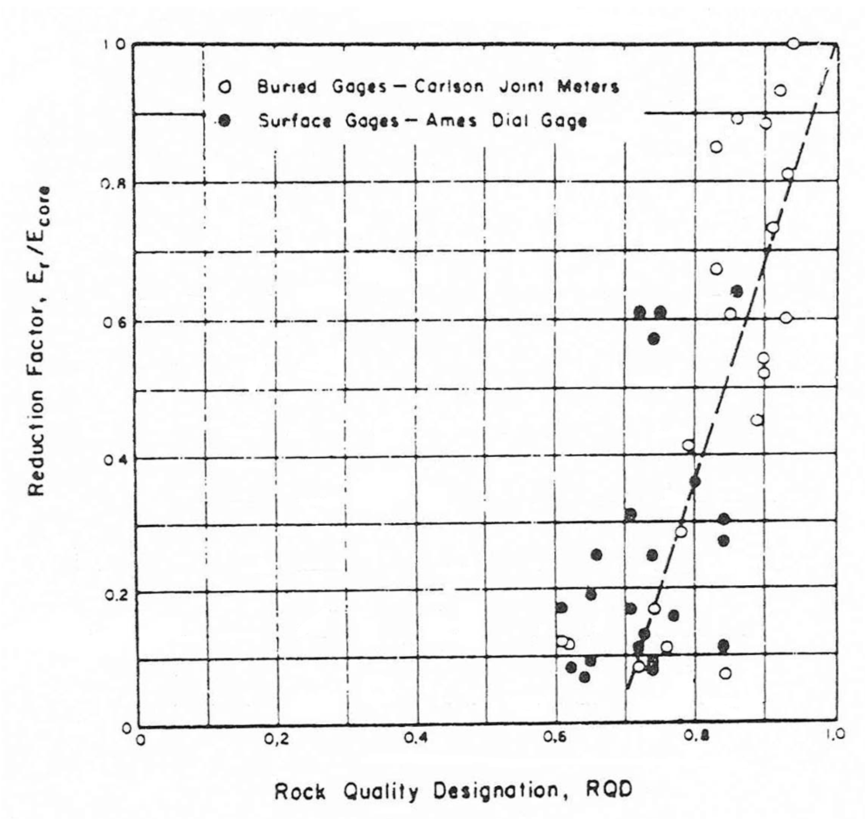
Water Inflow per Tunnel Length of 10 Meters (L/min)	or	Water Pressure within Joint/ Principal Stress	or	Ordinary Condition	Score
Not applicable		0		Completely dry	15
< 10		0.0 ~ 0.1		Humid	10
10 ~ 25		0.1 ~ 0.2		Wet	7
25 ~ 125		0.2 ~ 0.5		Water drops dripping	4
> 125		> 0.5		Fluid	0

Grades of Rock Quality by RMR

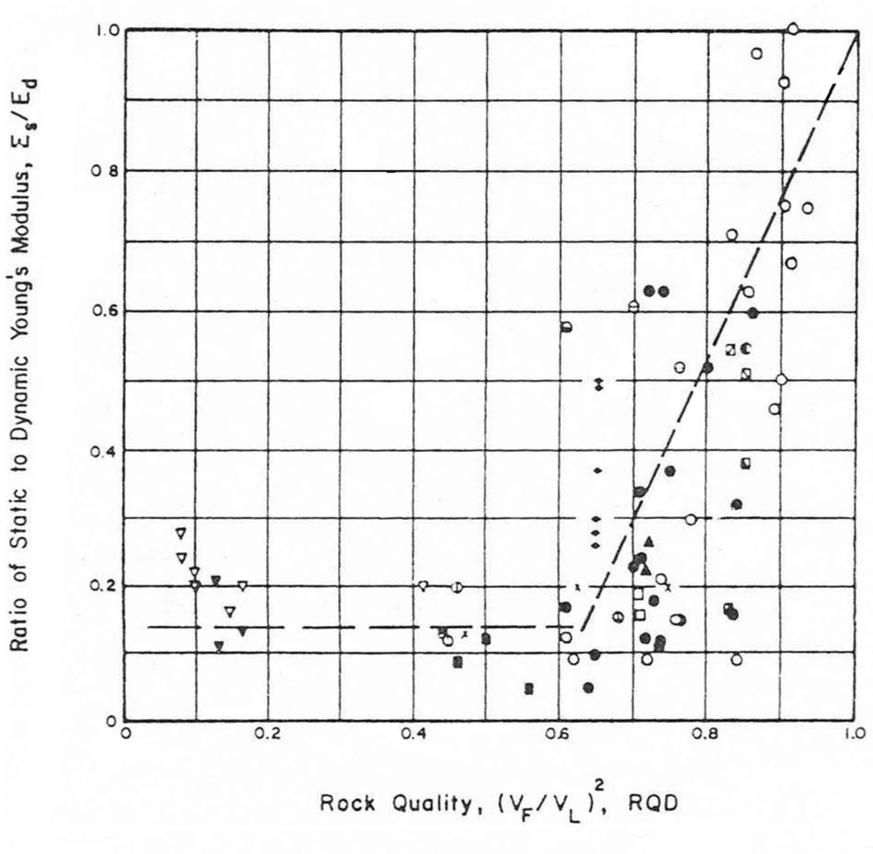
Grade	Rock Quality	RMR
I	Very good rock	81 ~ 100
II	Good rock	61 ~ 80
III	Fair rock	41 ~ 60
IV	Poor rock	21 ~ 40
V	Very Poor rock	0 ~ 20

Engineering properties of rocks

Rock mass deformation modulus determination using RQD and uniaxial compressive strength (Plate jacking Test at Dworshak Dam, Deer, 1967)



Rock mass deformation modulus determination using velocity index $(V_F/V_L)^2$ and modulus ratio (E_d/E_{50}) (Coon and Merritt, 1970)



Engineering properties of rocks

Example of rock mass deformation modulus determination

	XX Plant unit 1		XX Plant unit 2	
	Seismic Class I Struct.	Non-seismic Class I Struct.	Seismic Class I Struct	Non-seismic Class I Struct.
RQD(%)	2.41	2.17	2.07	1.65
RMR	3.80	2.20	2.60	2.00
In-situ Test	2.37	2.30	2.87	3.20
Velocity Index	2.08		2.01	
Index value(mean)	2.40		2.30	

Engineering properties of rocks

- Procedural example of unconfined compressive strength determination

Unconfined compressive test (#66)

Compressive strength determination as the mean value

Point load test first(#73), Second(#147)

Relationship bet. UCS and Point load index
$Qu = 34.27_{*}Is_{(50)}$(first), $Qu = 18.5_{*}Is_{(50)}$(second)

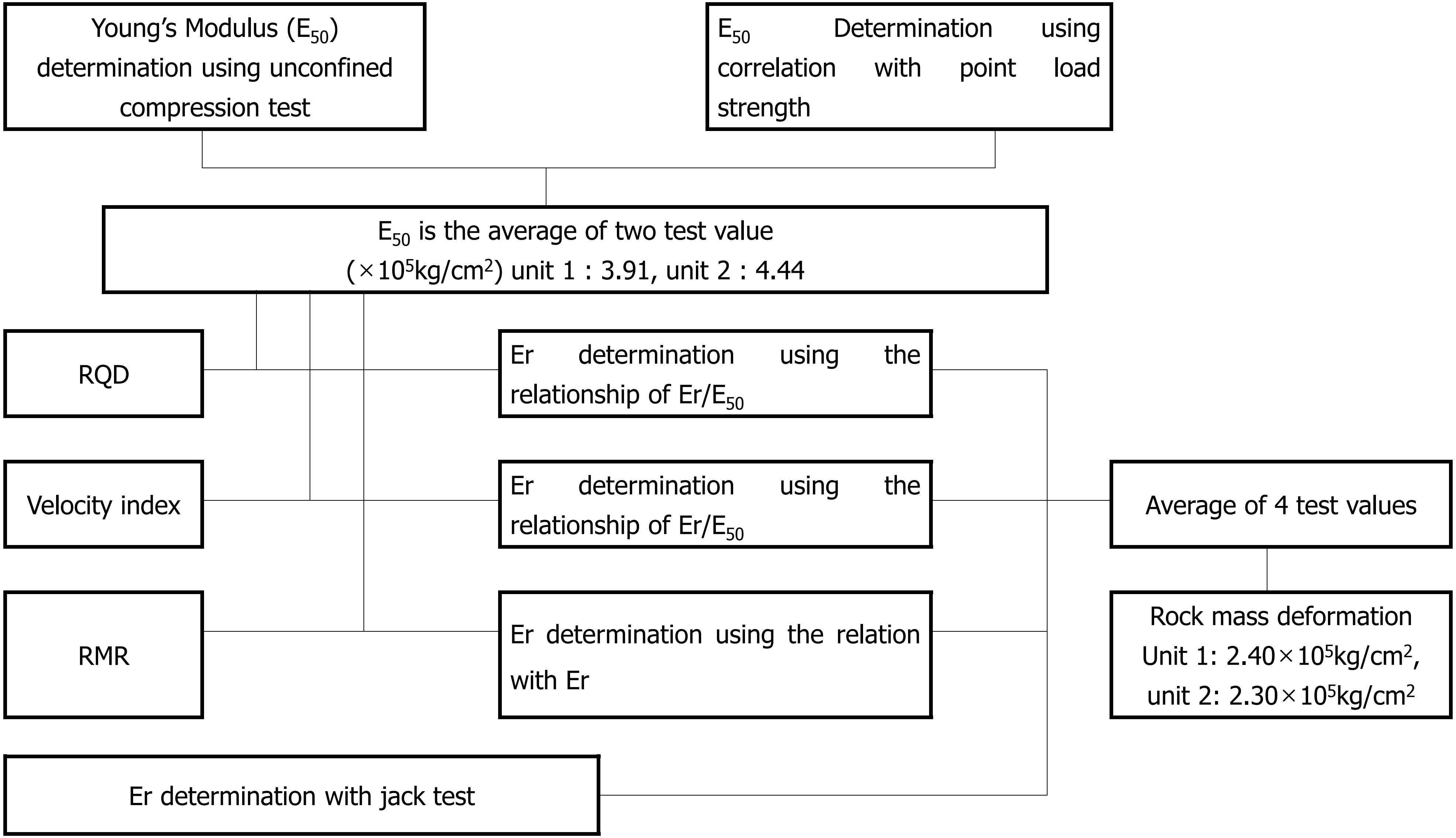
Compressive strength determination using the relationship of point load index and unconfined compressive strength

Average value of two test value

Unconfined compressive strength determination
Unit 1: 1,011 kg/cm^2, unit 2: 1,167 kg/cm^2

Engineering properties of rocks

- Procedural example of rock mass deformation determination



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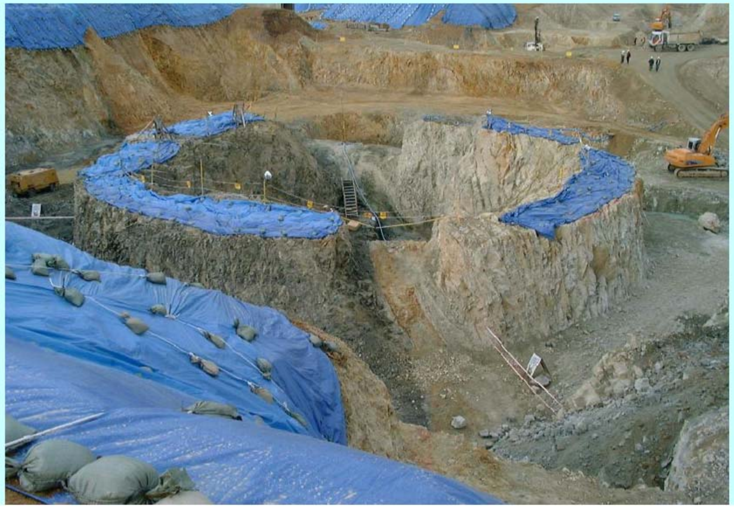
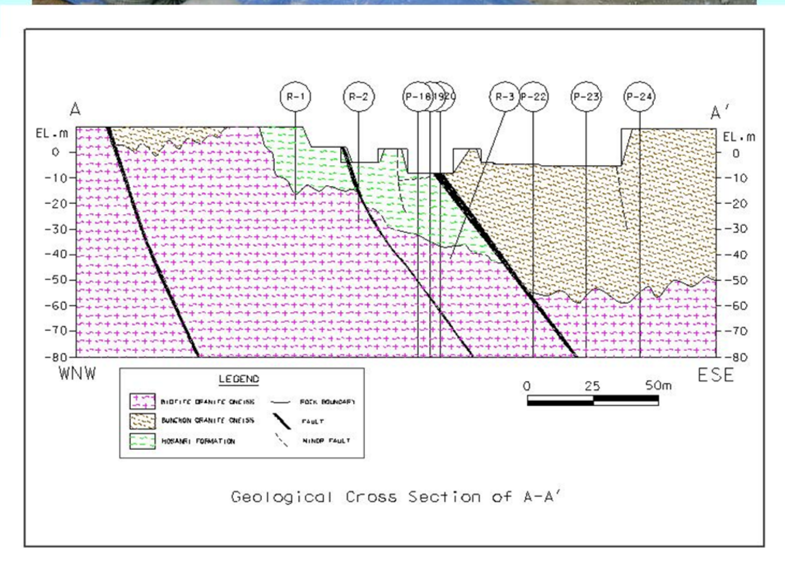
Foundation stability evaluation

❑ Procedure for foundation stability analysis





Foundation stability evaluation

- Velocity structure model
  - Development of the seismic response characteristics of foundation materials : site-specific response spectrum
  - If the s-wave velocity is equal or more than specified value, then the foundation assumed to be a **fixed base**
  - If the s-wave velocity is less than specified value, then the **soil structure interaction (SSI)** analysis should be conducted
    - The material with s-wave velocity less than specified value does not mean unsuitable for foundation materials

Foundation stability evaluation

Bearing capacity (Qa) evaluation (CGS)

For rock site

- Qa = Ksp X Qu-core

Qa: allowable bearing pressure,

Qu-core: average unconfined compressive strength of rock cores(ASTM D2938),

Ksp : an empirical coefficient, which include safety factor of 3 and ranges from 0.1 to 0.4

Spacing of discontinuities	Ksp	Spacing width (m)
Moderately close	0.1	0.3 - 1
Wide	0.25	1 - 3
Very Wide	0.4	> 3

Foundation stability evaluation

Settlement evaluation for rock site

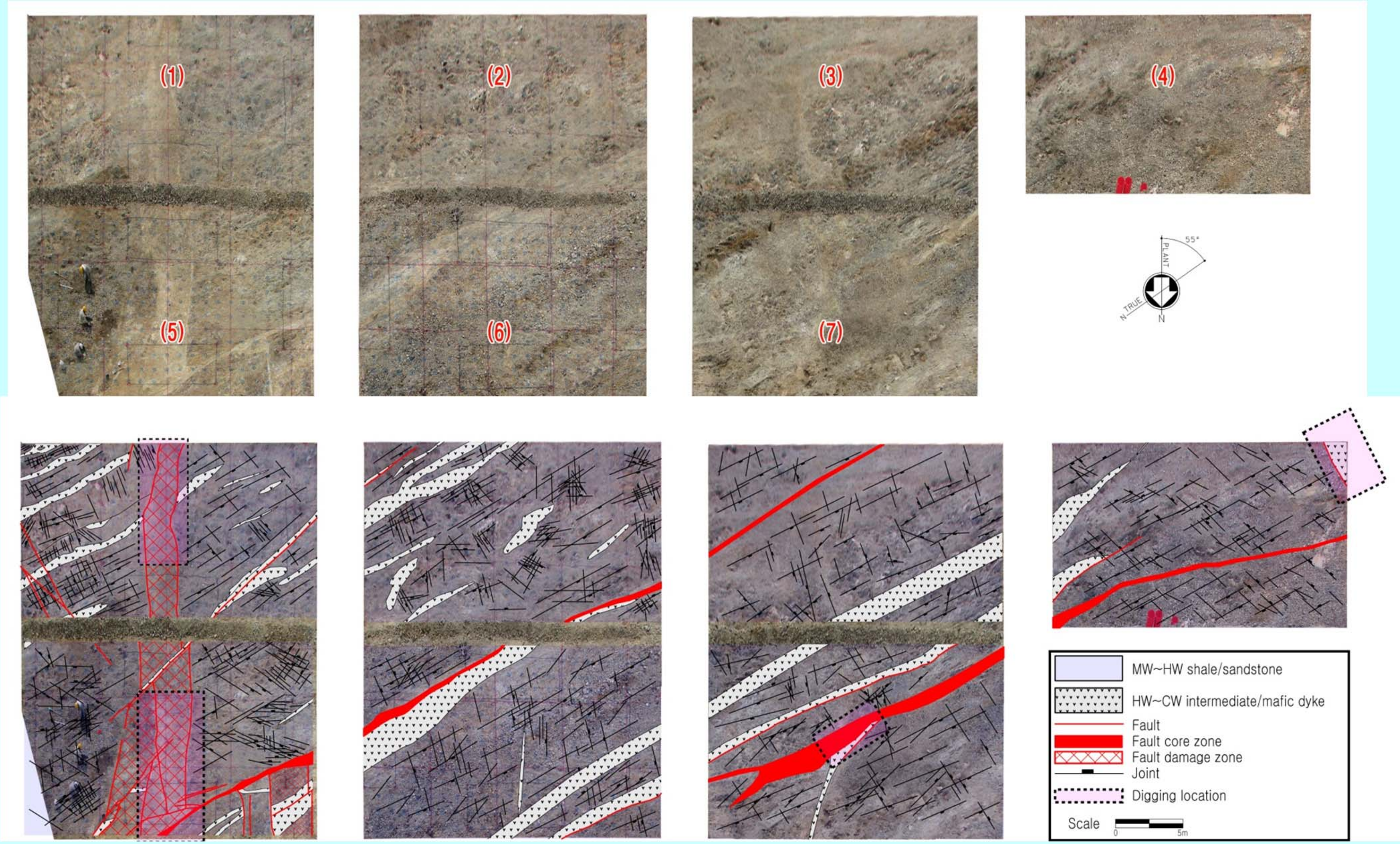
$$\rho = \frac{P(1-\nu_m^{\ 2})}{\beta_Z E_m A^{0.5}} \qquad \rho = \frac{0.9P}{E_m A^{0.5}} = \frac{0.9P}{\alpha_E E_r A^{0.5}} \qquad \alpha_E = \frac{Ei}{Er}$$

- P: load, νm : poisson's ratio of rock, *E*m: young's modulus of rock, *A*: foundation area, βz: foundation shape coefficient
- For rock site, the settlement may negligible
- Computer simulation, 1.0 inch is accepted as allowable criteria
- In case of differential settlement, the safety of pipes between Structures should be considered

Liquefaction potential evaluation

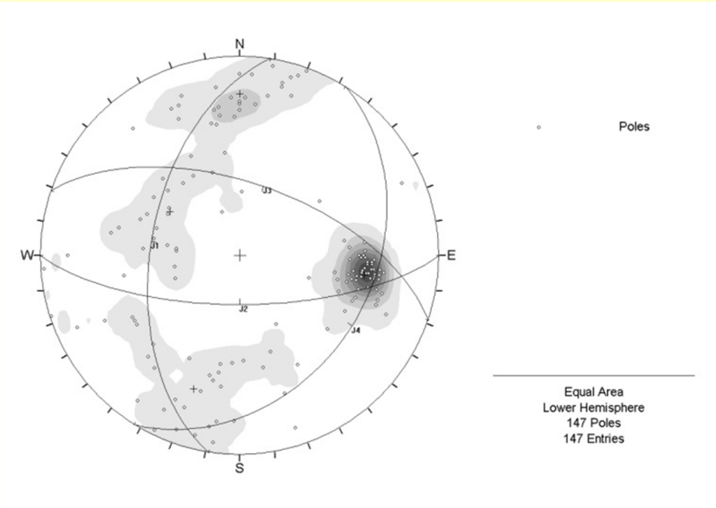
- When the site is composed of rock materials, then this analysis is not needed

Foundation Stability Evaluation

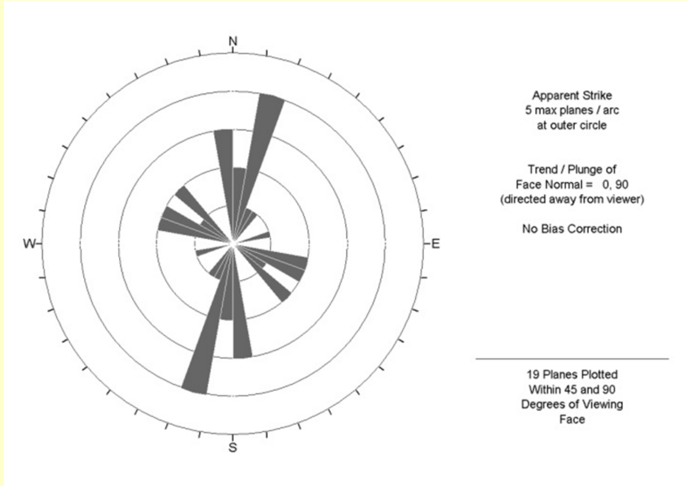


Geological and geotechnical map of foundation material

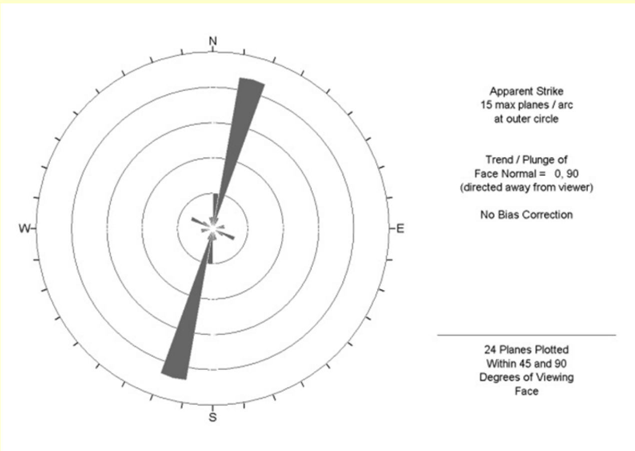
Foundation Stability Evaluation



Development of discontinuities in foundation rock



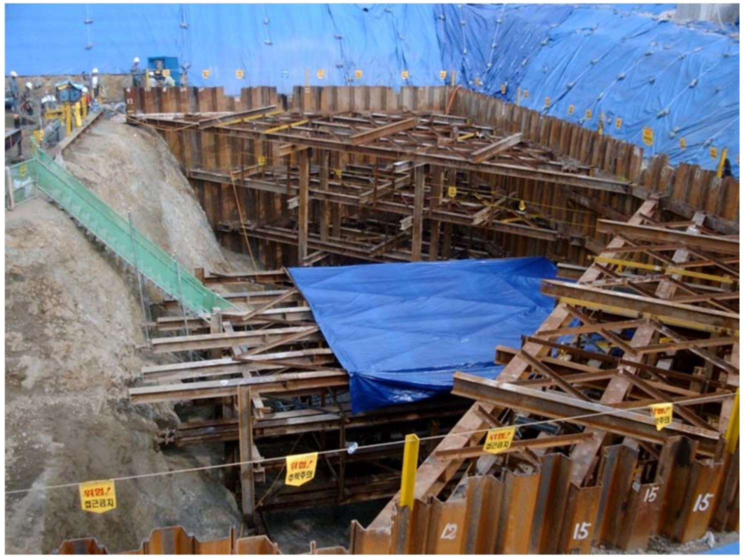
Rose diagram of fault in the foundation rock

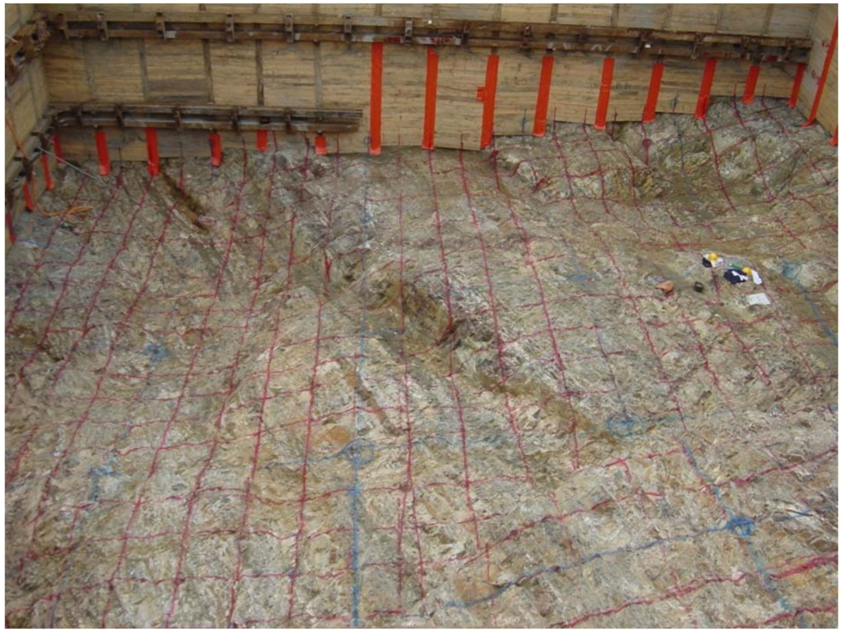


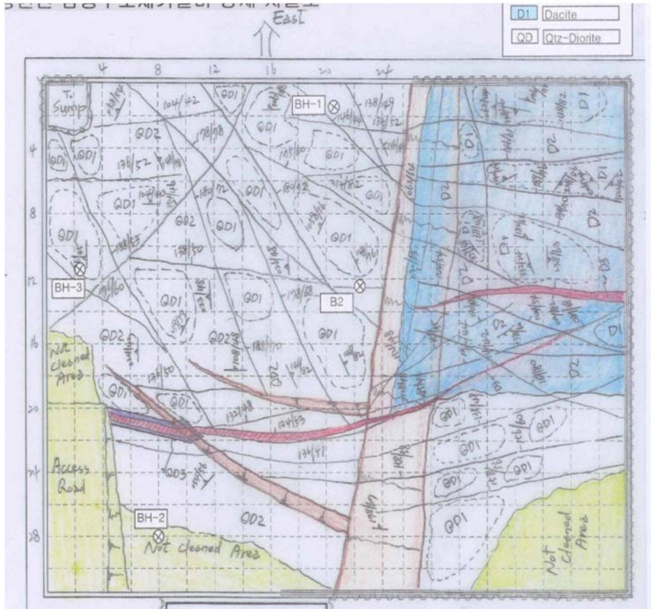
Rose diagram for dykes in the foundation rock

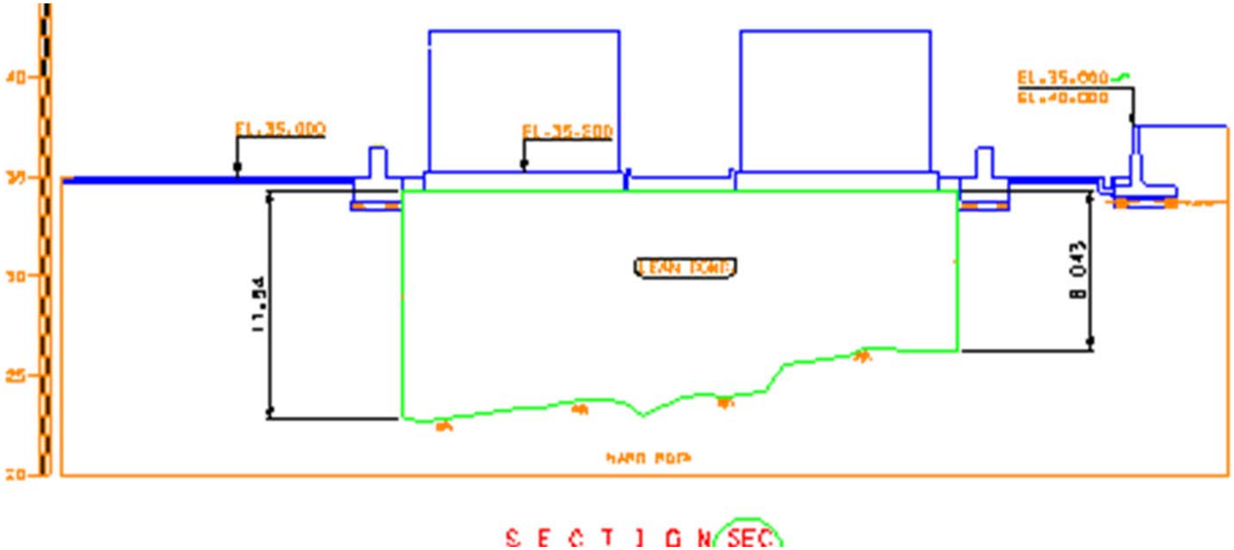
Foundation stability evaluation

Improvement of unsuitable foundation and slope materials









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Basic Information

Design considerations of Foundation

Engineering properties of rocks

Foundation stability evaluation

Slope stability evaluation

Slope stability evaluation

- Evaluation of slope stability
  - Slopes are divided into rock slope and soil slope type
  - Different evaluation methods are applied according to the slope type
  - Static and dynamic analysis shall be conducted
  - Special attention should be paid to the temporal slope such as cut slope during construction
- Basic information (Data requirements)
  - Dimensions and the type of slope
  - Geologic characteristics especially information about discontinuities
  - Grounder water condition
  - Geophysical exploration results
  - Borehole logging and borehole 3-D images

Slope stability evaluation

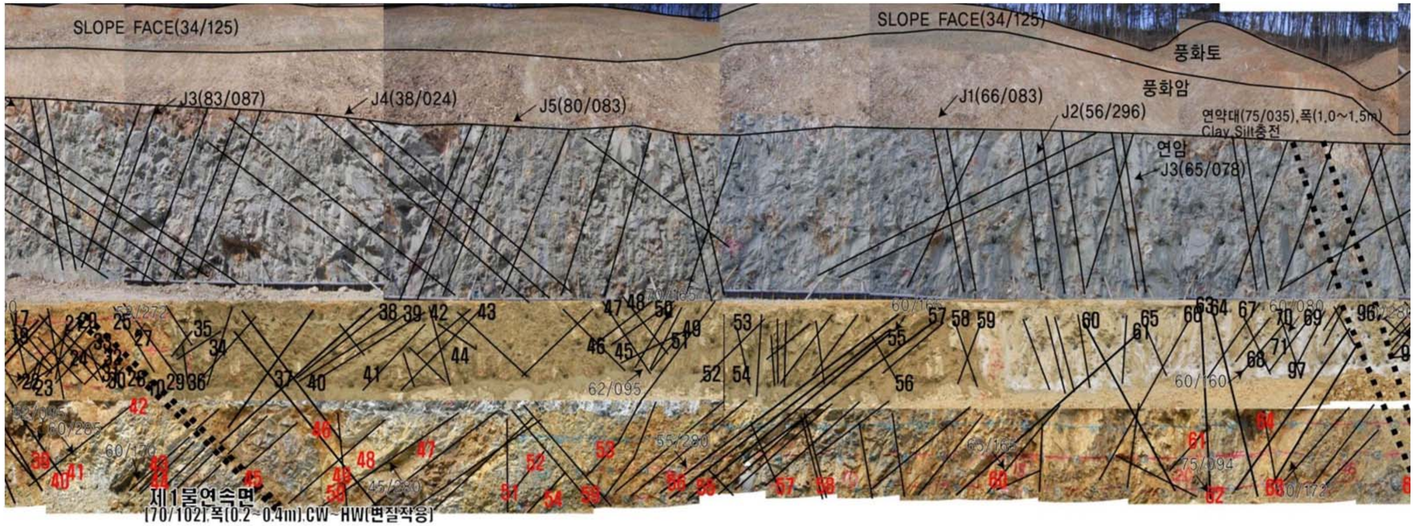
- Analysis of slope stability
  - For soil slope the factor of safety has minimum value of 1.5 in static analysis and of 1.2 in dynamic analysis
  - For rock site numerical analysis and stereo net-based graphic analysis is possible

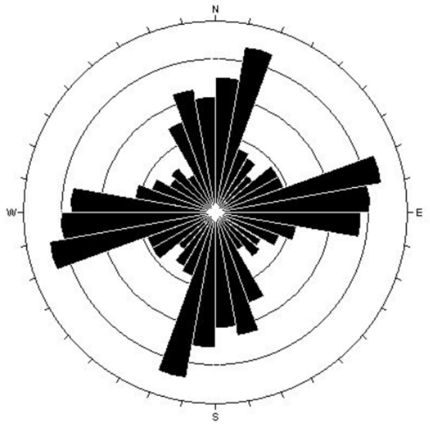
- Treatment of unstable slope
  - Lowering the slope angle, drainage, anchoring, rock bolting, grouting, shot-crete, etc.

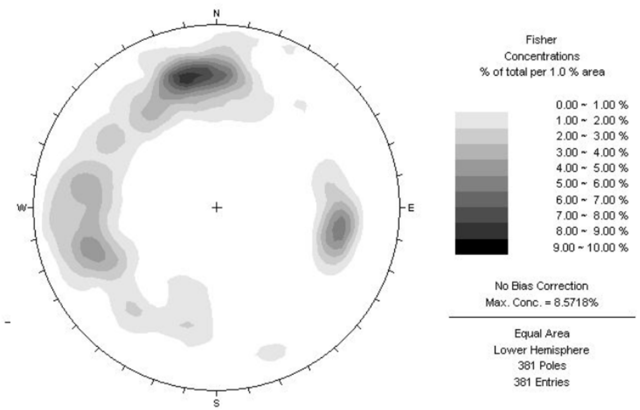
- Monitoring of long-term slope stability
  - Monitoring of groundwater condition, slope angle, etc

Slope stability evaluation

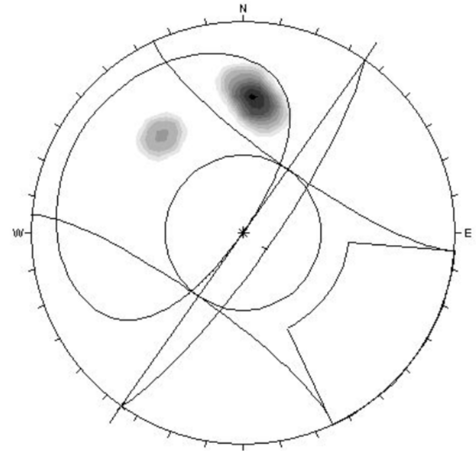
- Example of surface geological map for slope stability analysis

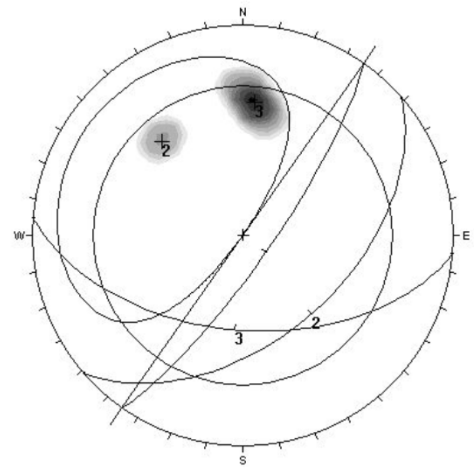






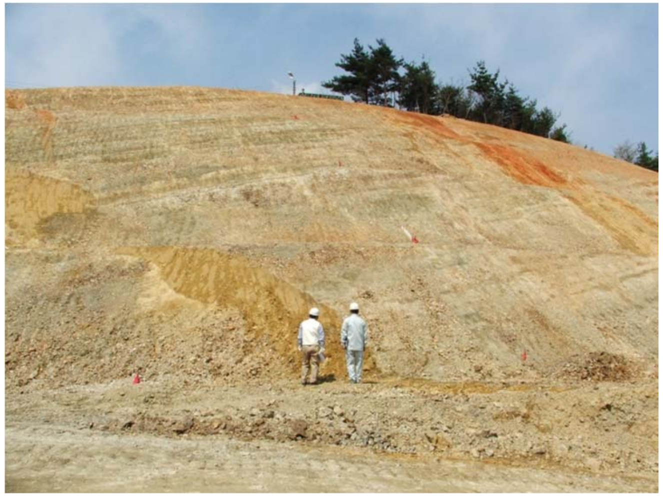
- Example showing plan and wedge failure analysis results





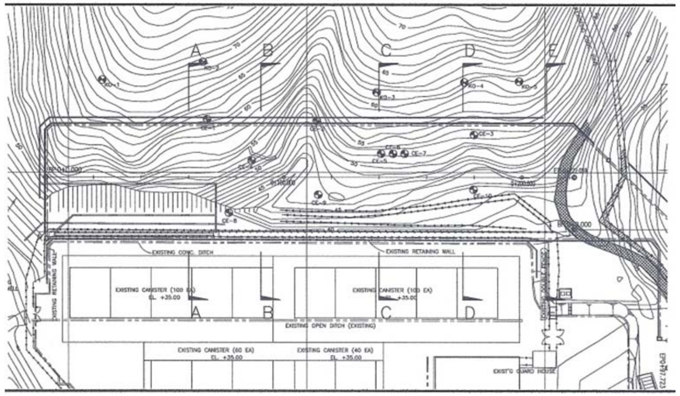
Slope stability evaluation

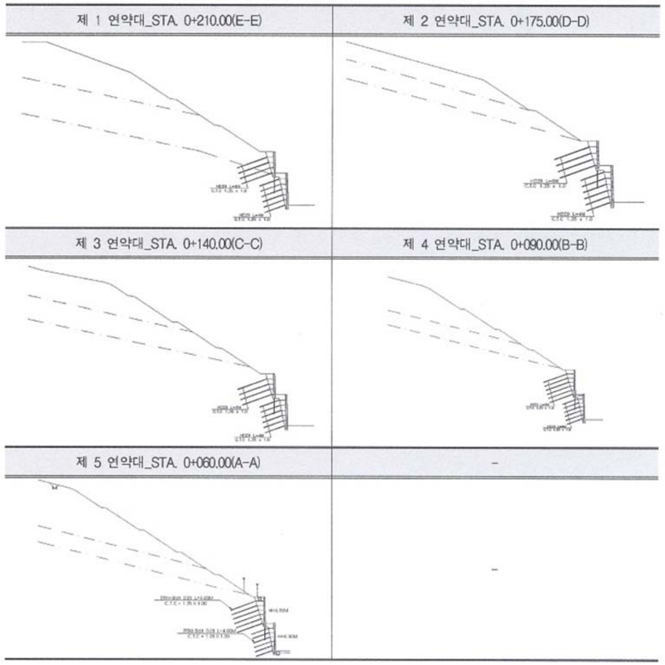
Detailed on-site slope investigation

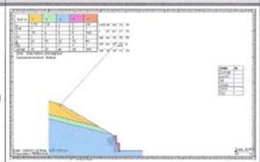
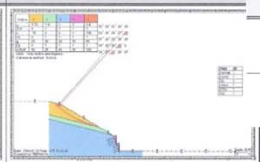


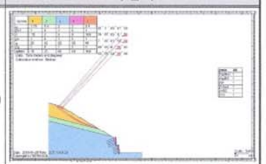


Slope stability evaluation

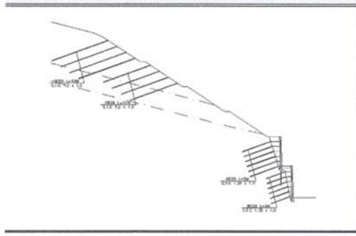
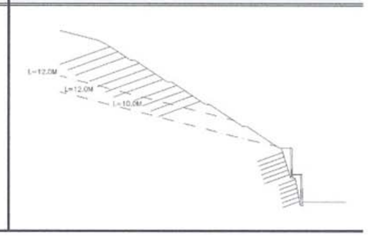




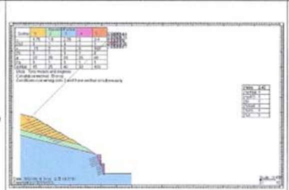
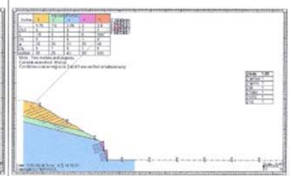
구 분	건기시	우기시
제 5연약대 STA. 0+060		
해석결과	F.S = 0.74 < 1.50 NG	F.S = 0.25 < 1.20 NG

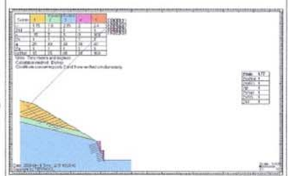
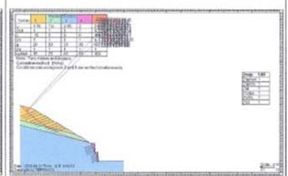
구 분	지진시
제 5연약대 STA. 0+060	
해석결과	F.S = 0.58 < 1.10 NG

구 분	단위중량(γ)	내부마찰각(°)	점착력(c)	비 고
붕적층(점성토)	1.75t/㎥	20	0.15t/㎡	
풍 화 토	1.90t/㎥	30	2.0t/㎡	
풍 화 암	2.00t/㎥	32	3.0t/㎡	
연 암 (절리면전단강도)	2.35t/㎥	33	3.0t/㎡	
뒤채움 골재	2.00t/㎥	35	0.0t/㎡	
블록벽체(콘크리트)	2.40t/㎥	40	100.0t/㎡	

제 4연약대 보강검토 단면도	제 5연약대 보강검토 단면도
	

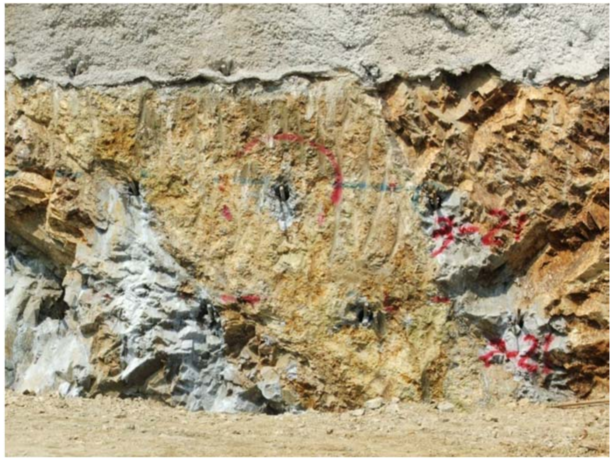
구 분	보강방법	길 이	보강간격	비 고
1, 2 단 사면	Nailling	12.0m	1.2×1.2m	1단사면 3줄 2단사면 4줄
3 단 사면	Nailling	10.0m	1.2×1.2m	4줄

구 분	건기시	우기시
제 5연약대 STA.0+060		
해석결과	F.S = 2.42 > 1.50 O.K	F.S = 1.38 > 1.20 O.K

구 분	지진시(0.2g 고려)	지진시(0.25g 고려)
제 5연약대 STA.0+060		
해석결과	F.S = 1.77 > 1.10 O.K	F.S = 1.66 > 1.20 O.K

Slope stability evaluation




On-site inspection for the treatment of slope

•Closure

Thank you for your attention!