10. Application to stability of rock slope

‡:このマークが付してある著作物は、第三者が有する著作物ですので、同著作物の再使用、同著作物の二次的著作物の創作等については、著作権者より直接使用許諾を得る必要があります。

Rock slope

- Natural slope
- Cut slope for roadway etc.
- Bench cut slope in open pit mine

Open pit mine

- Coal
- Limestone
- Aggregate

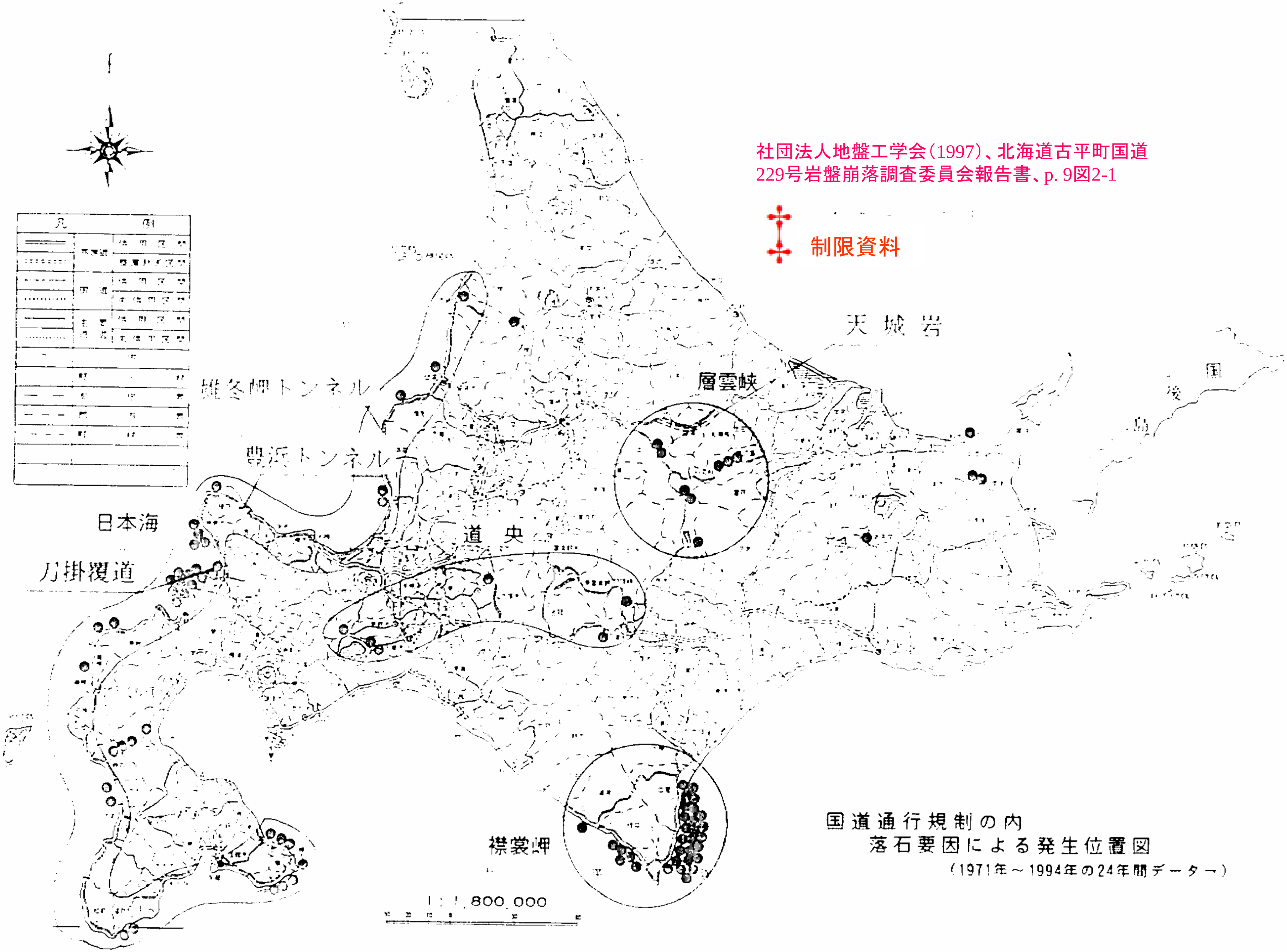
- Bench cut

著作権処理の都合で、
この場所に挿入されていた
写真を省略させて頂きます。

10.1 Outline

Site	Prefecture	Date	Movement	Volume (m^3)	Inclination	Rock type
Tenninkyo	Hokkaido	1980, 10/16	Slide	20,000	80	Welded tuff
Ofuyumisaki	Hokkaido	1981, 12/19	Slide	240,000	80	Pyroclastic rock
Souunkyo	Hokkaido	1987, 6/9	Fall	11,000	80	Welded tuff
Echizenmisaki	Fukui	1989, 7/16	Toppling	1,000	90	Pyroclastic rock
Sarunagi	Nagano	1991, 10/18	Fall	3,000	80	Slate chert
Katanakake	Hokkaido	1993, 7/12	Slide-fall	2,000	80	Pyroclastic rock
No.2 Shiraito	Hokkaido	1993, 7/12	Fall	2,500	80	Pyroclastic rock
Tanihana	Niigata	1995, 4/2	Fall	5,000	70	Rhyolite
Toyohama	Furubira	1996, 2/10	Fall	11,000	80	Pyroclastic rock
No.2 Shiraito	Shimamaki	1997, 8/25	Slide-toppling	42,000	75	Pyroclastic rock

Slope collapse whose volume was more than 10000 m^3 between 1980 and 2001except for mine accidents (Ueno and Yamagichi, 2002)



社団法人地盤工学会(1997)、北海道古平町国道
229号岩盤崩落調査委員会報告書、p. 9図2-1

制限資料

国道通行規制の内
落石要因による発生位置図
(1971年～1994年の24年間データー)

10.2 Examples of rock slope collapse

Toyohama (Investigation Committee for Rock Slope Collapse at Toyohanma Tunnel in Furubira, Hokkaido, 1997, volume is 11,000 m^3)

社団法人地盤工学会(1997)、北海道古平町国道229号岩盤崩落調査委員会報告書、p. 5写真1-1

Rock slope collapse at No. 2 Shiraito Tunnel (Investigation Committee for No. 2 Shiraito Tunnel, 1998, volume is 56,000 m^3)

著作権処理の都合で、
この場所に挿入されていた

『北海道新聞　第二白糸トンネルの
岩盤崩壊記事の写真』を省略させて
頂きます。

Rock slope cpllapsee at Sunago Coal Mine. A bench is 10 m high, volume is 13,500 m^3

Helicopter investigation around Shakotan Peninsula in 1998

http://rock.eng.hokudai.ac.jp

Investigation in Hiroo Town after Tokachi-oki Earthquake in 2003

univ., JAPAN

http://rock.eng.hoku

Helicopter investigation in Hama Kotanuka and Churui in 2004


2004. 10. 13


2004. 10. 13

10.3 Geometry of rock slope failure

General classification

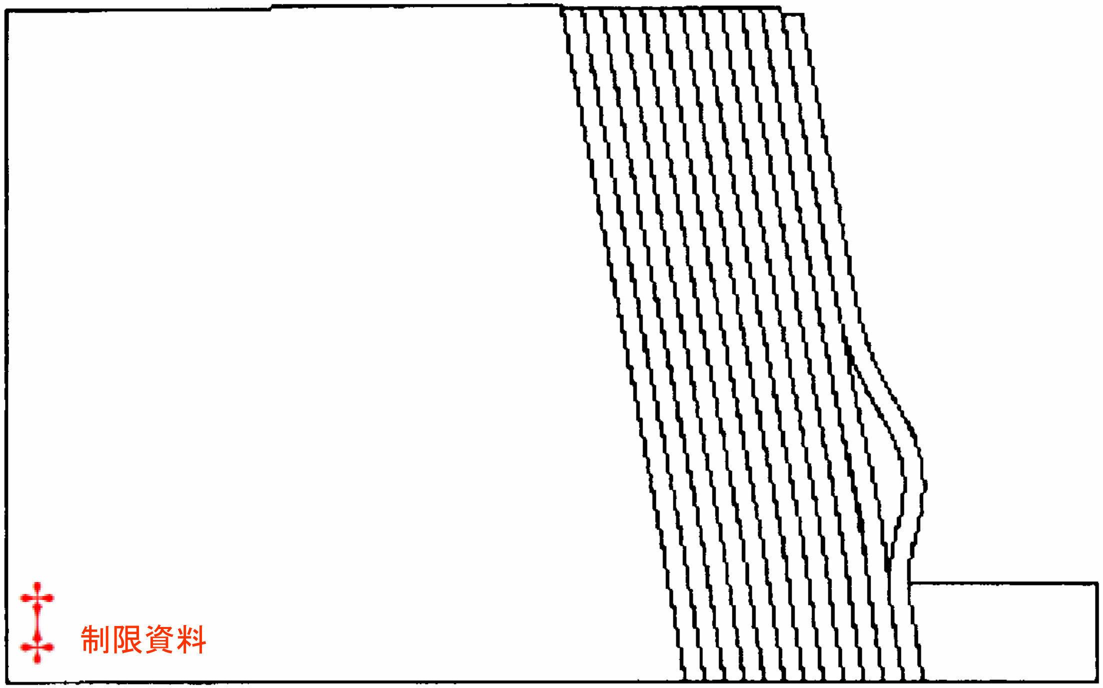
Geometry of rock slope collapse (Goodman, 1980). (a)：Plane slide, (b)：wedge slide, (c)：toppling

著作権処理の都合で、

この場所に挿入されていた

『Goodman (1980), Introduction to Rock Mechanics, John Wiley and Sons, p. 256, Fig. 8.1』

を省略させて頂きます。



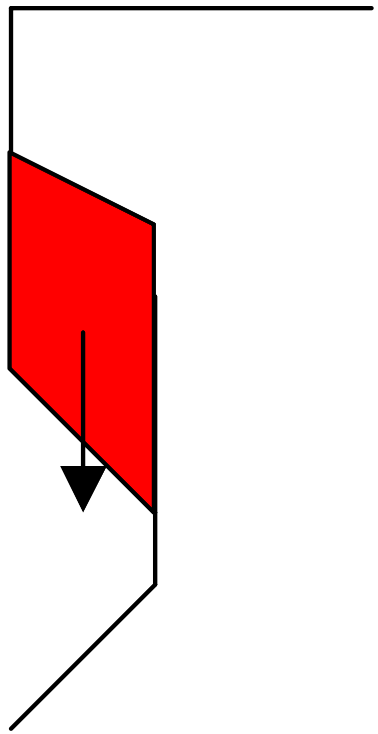
Toppling failure (Pant and Adhikary, 1999)

Reprinted from Rock Mech. Rock Engng, 1999, Vol. 32, No. 2, p.161, Fig. 3a, Pant, S. R. and Adhikary, D. P., Implicit and Explicit Modeling of Flexural Buckling of Foliated Slopes, pp. 157-164., with permission from CSIRO.

For Shakotan Peninsula （Investigation Committee for Toyohama Tunnel Accident, 1997）

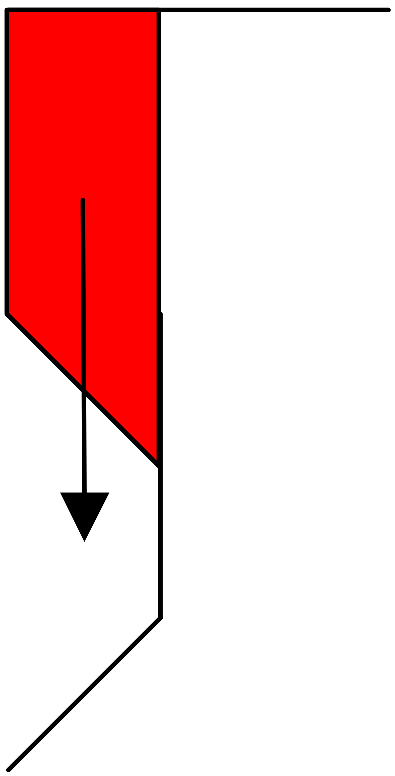
Detachment-sliding down type

- Fracture grows upward
- Weathered detachment plane is vertical or steeply inclined
- Size of falling rock block is 1 m to 10 m
- Overhang geometry



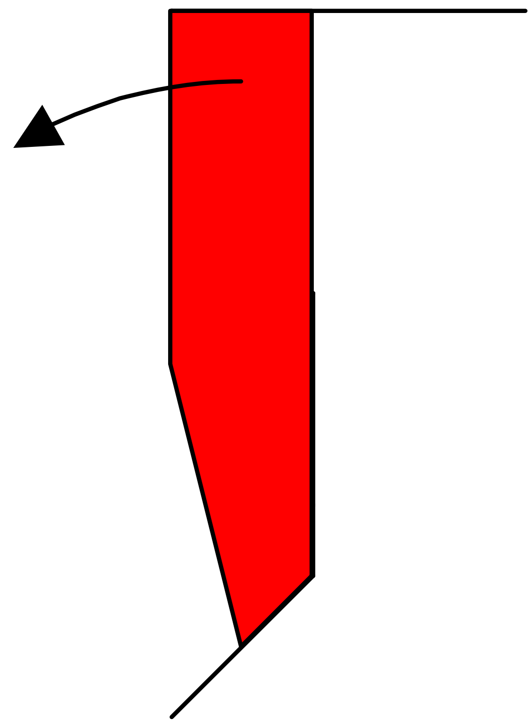
Sliding down type

- Fracture grows upward
- Weathered detachment plane is vertical or steeply inclined
- Size of falling rock block is several meters to 10 m
- Overhang geometry



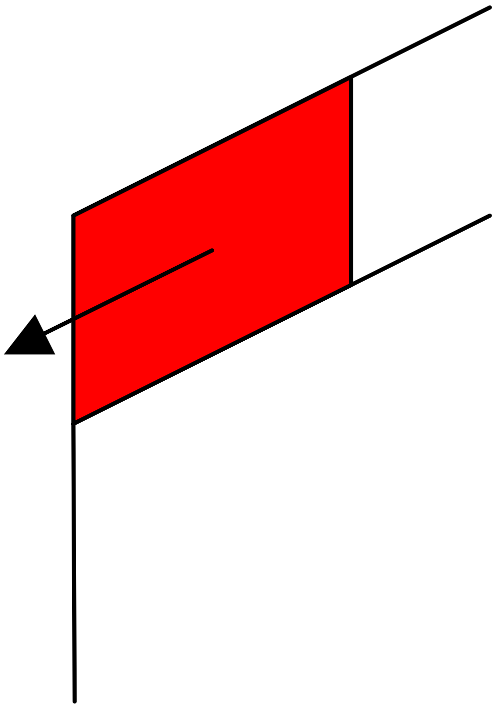
Toppling type

- Fracture grows downward
- Weathered detachment plane is vertical or steeply inclined
- Size of falling rock block is several meters to several ten meters



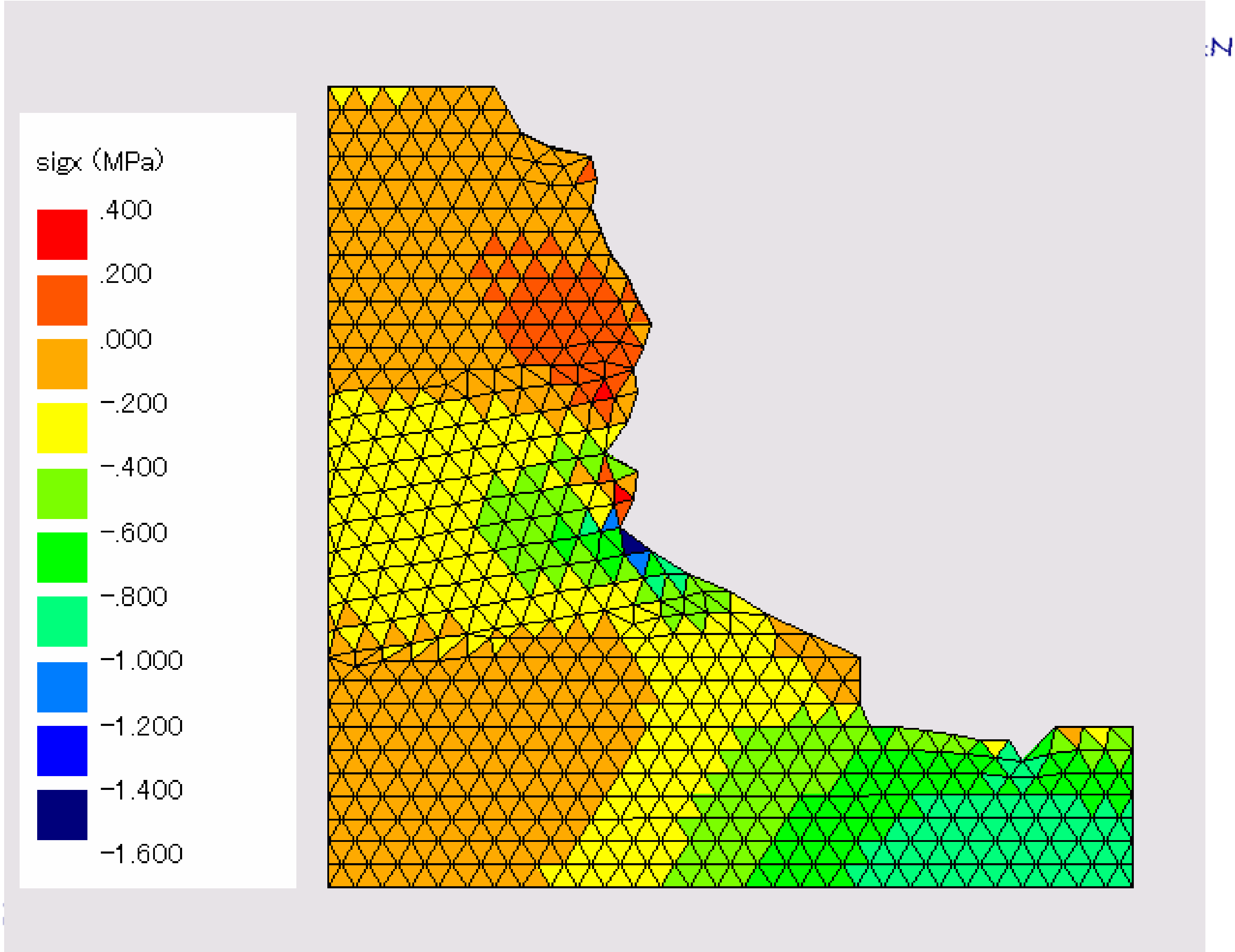
Slide type

- Fractures grow upward and downward
- Weathered detachment planes are vertical and horizontal
- Falling rock block is between 1 m and several ten meters.



10.4 Causes of rock slope collapse （Investigation Committee for Toyohama Tunnel Accident, 1997）

- Topography
  - Steep cliff, overhang
- Geology, rock type and weathering
  - Igneous rocks
    - Hard and strong, but discontinuous
  - Pyroclastic rocks
    - Soft and weak
    - Less fractures, but easily weathered
- Weather
  - Rain
  - Temperature variation
  - Freeze-thaw cycle
- Ground water
  - Pore pressure
- External forces
  - Earthquake
  - Erosion by sea wave


sigx (MPa)
.400
.200
.000
-.200
-.400
-.600
-.800
-1.000
-1.200
-1.400
-1.600

10.5 Criterion for rock slope collapse

Plane slide
(Limit equilibrium method)

$$W\sin\beta = CA + W\cos\beta\tan\phi$$

W Weight of rock block

$$= \gamma\left(\frac{1}{2}H\cdot\frac{H}{\tan\alpha} - \frac{1}{2}\frac{H}{\tan\alpha}\frac{H}{\tan\alpha}\tan\beta\right)$$

$$= \frac{\gamma H^2}{2\tan\alpha}\left(1 - \frac{\tan\beta}{\tan\alpha}\right)$$

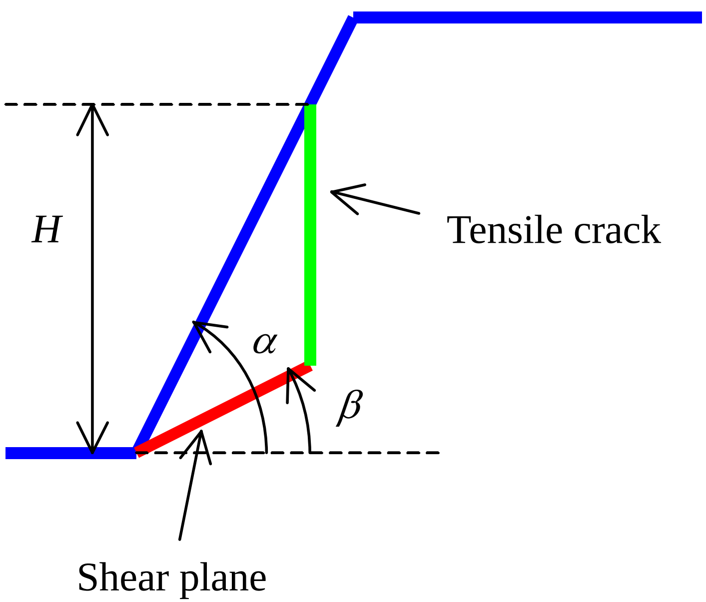
γ Unit volume weight

C Cohesion

A Area of shear plane

$$= \frac{H}{\tan\alpha\cos\beta}$$

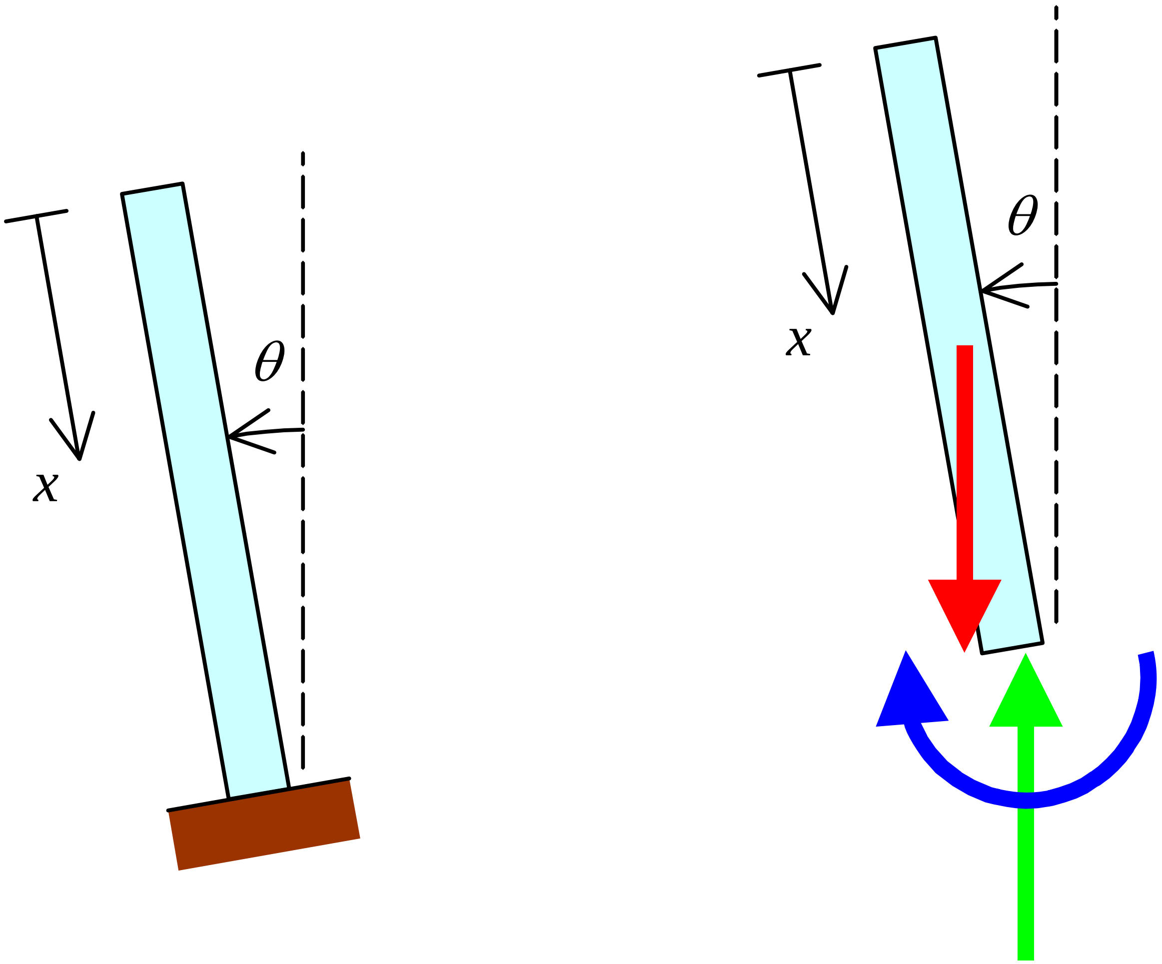
ϕ Friction angle



Example

- Calculate possible maximum *H* when cohesion is 10 MPa, friction angle is 30 degree, unit volume weight is 27 kN/m^3、α = 60 (degree) and β = 30 (degree).
- Answer: 208 m

Toppling

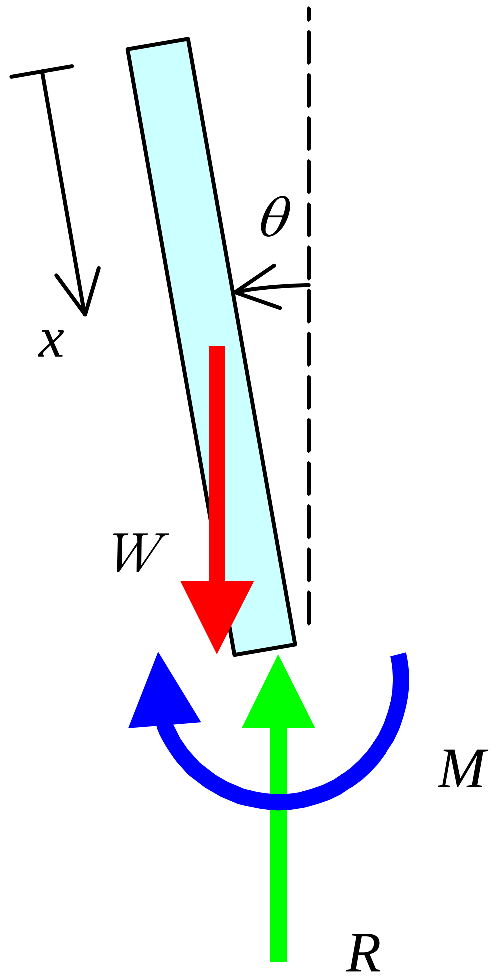


Weight of the rock is

$$W = \gamma bhl.$$

where b, h, l is thickness, width, length of the rock, respectively. Ignoring the bending moment due to deformation of the rock for convenience, the bending moment at $x = l$ is

$$M = \frac{1}{2}\gamma hbl^2 \sin\theta$$

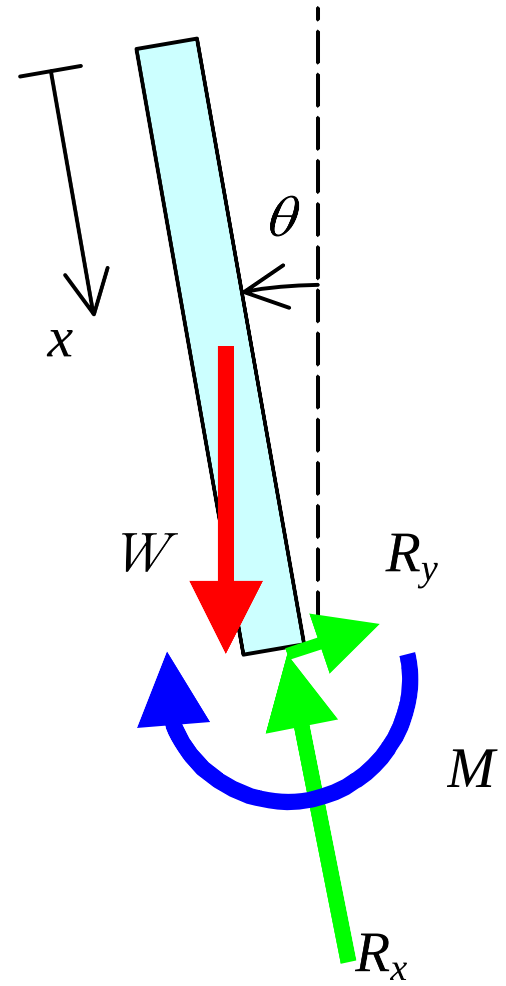


The reaction in the axial direction is

$$R_x = \gamma hbl \cos\theta$$

Taking tensile stress as positive, the axial stress due to the reaction is

$$\sigma_{\mathrm{R}} = -\gamma l \cos\theta$$



Remember

$$\sigma_M = \frac{My}{I_z}$$

where σ_M is stress by bending moment, y is the distance from the neutral axis and I_z is the momentof inertia. Therefore, the stress at $x = l$ becomes

$$\sigma = \sigma_M + \sigma_C = \frac{1}{2}\gamma hbl^2 \sin\theta \frac{h}{2}\frac{12}{bh^3} - \gamma l \cos\theta$$

$$= \gamma l\left(\frac{3l}{h}\sin\theta - \cos\theta\right)$$

Example

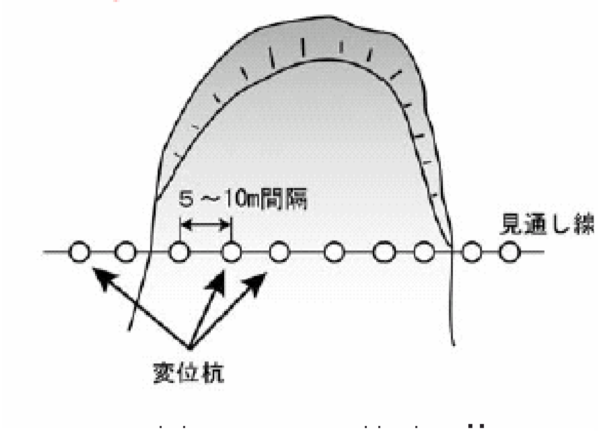
- Calculate angle at which toppling occur in he case where unit volume weight is 27 kN/m^3, length is 100 m, width is 5 m and tensile strength of rock mass is 5 MPa.
- Answer：3 degree

10.6 Monitoring of rock slope (Hokkaido Development Bureau, 2004)

Simple measurement

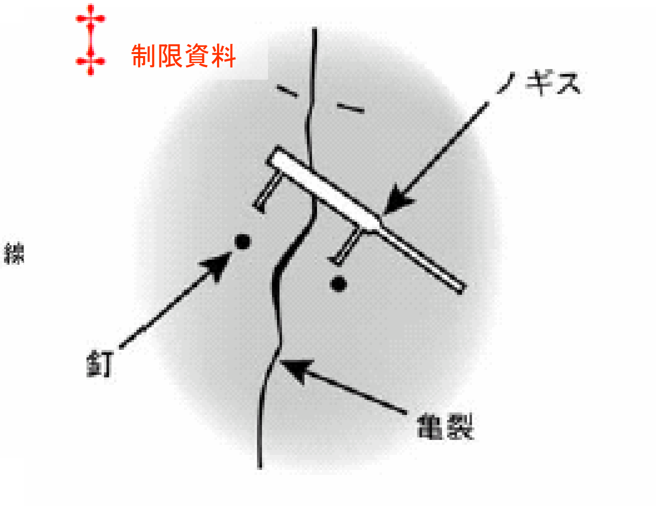
北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-3-3

制限資料



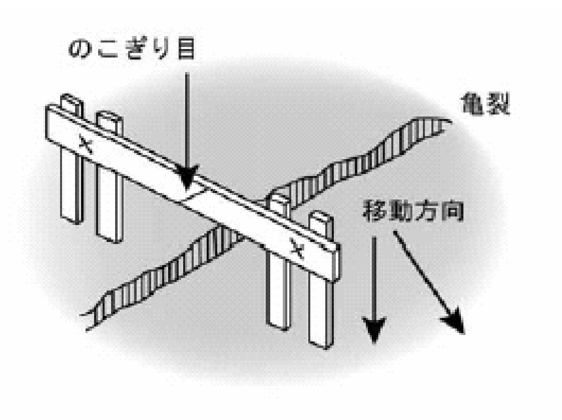
北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-10図6-3-4

制限資料



北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-10図6-3-5

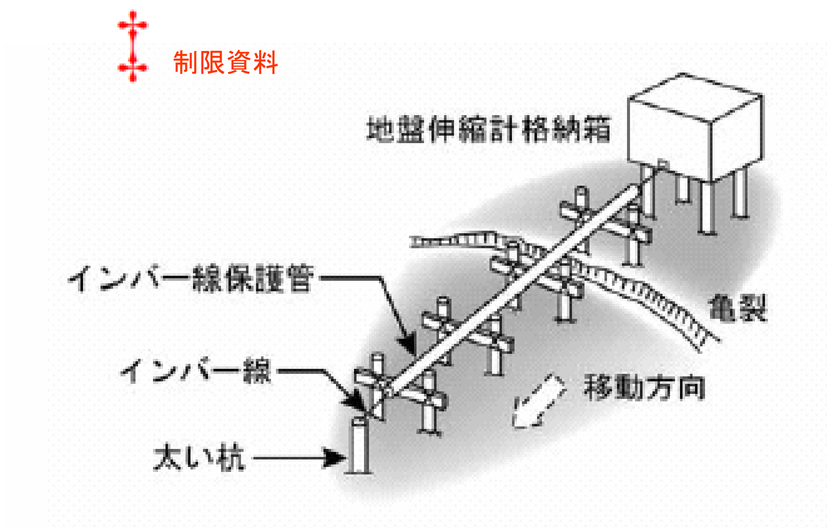
制限資料



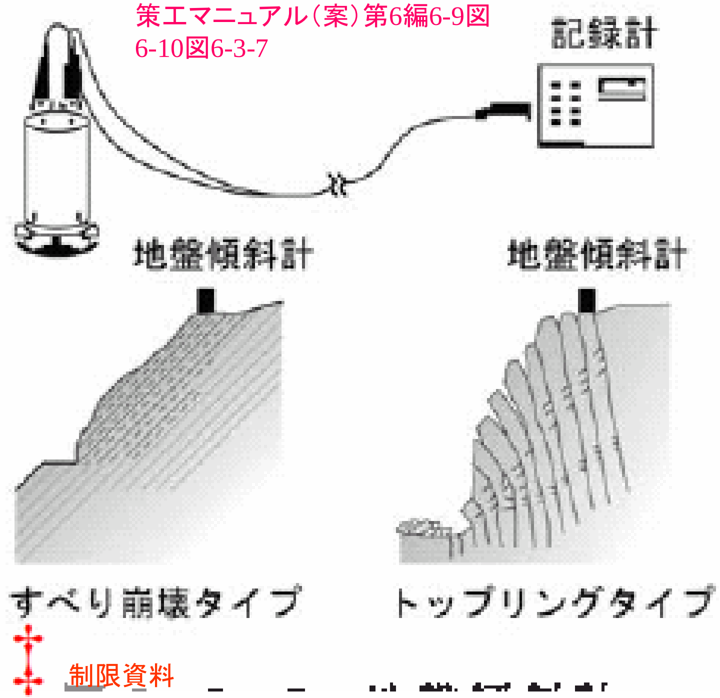
Deformation　　Fracture opening　　Relative displacement

Measurements using instruments

北海道開発局建設部道路建設課、
北海道における岩盤斜面対策エマ
ニュアル（案）第6編6-9図6-10図6-3-6



北海道開発局建設部道路建設
課、北海道における岩盤斜面対
策エマニュアル（案）第6編6-9図
6-10図6-3-7

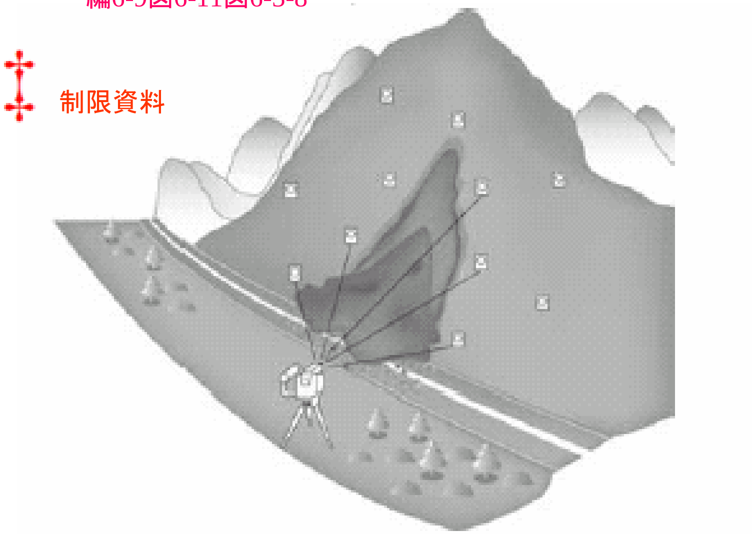


Strain of rock mass

Tilt of rock mass

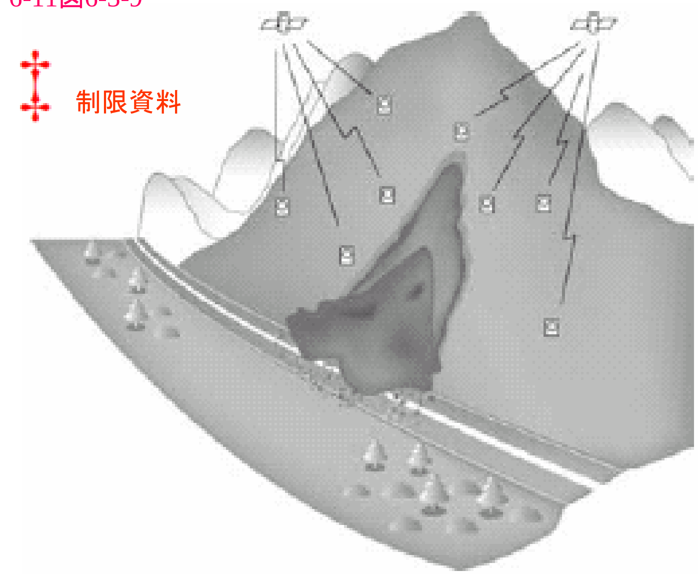
Measurements using instruments

北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-11図6-3-8



Laser survey

北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-11図6-3-9

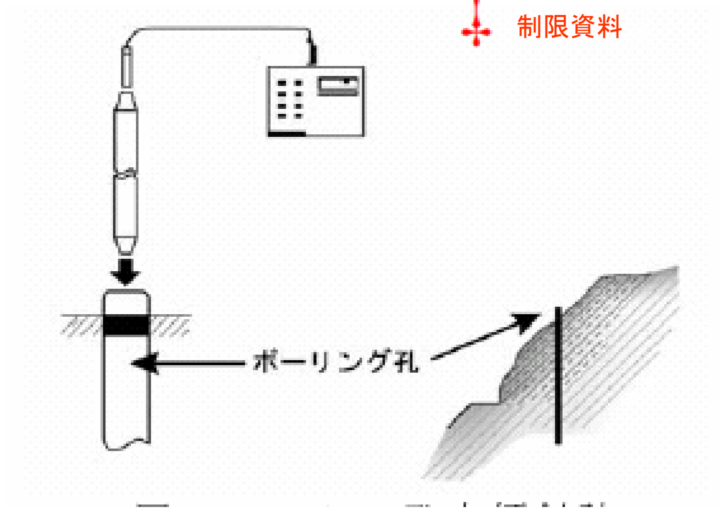


GPS

Measurement in rock mass by using instruments

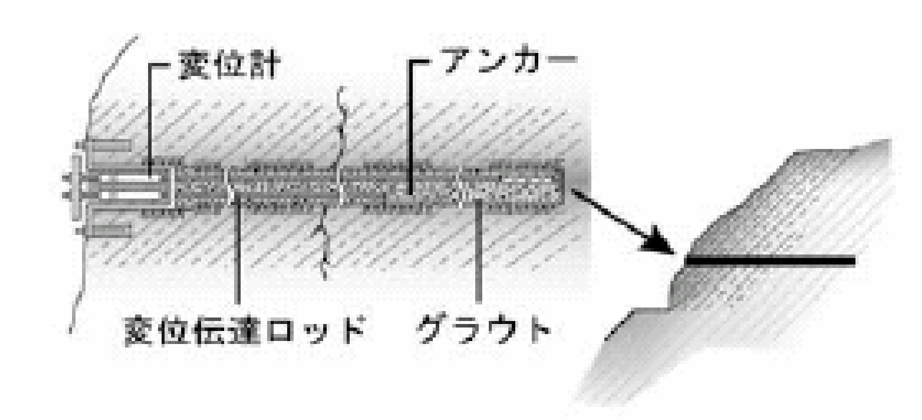
北海道開発局建設部道路建設課、北海道における岩盤斜面対策工マニュアル（案）第6編6-9図6-11図6-3-10

制限資料



北海道開発局建設部道路建設課、北海道における岩盤斜面対策工マニュアル（案）第6編6-9図6-11図6-3-11

制限資料



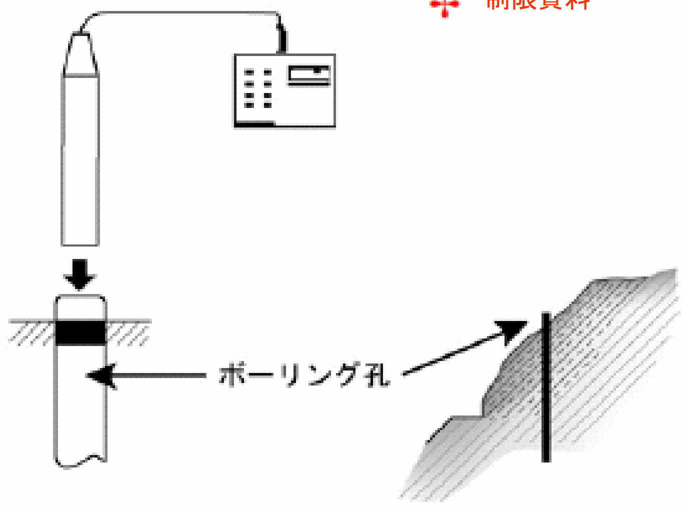
Borehole tiltmeter

Rock mass deformation

Measurement in rock mass by using instruments

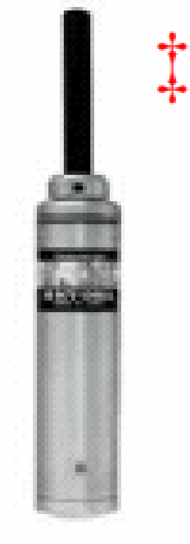
北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-12図6-3-12

制限資料



北海道開発局建設部道路建設課、北海道における岩盤斜面対策エマニュアル（案）第6編6-9図6-12写真6-3-2

制限資料



Pipe type-strainmeter

Water level

10.7 Prediction of rock slope collapse

Many dangerous slopes

- When does it fall?

An overhang rock at Monami Park in Sapporo

Prediction using displacement rate

- dt/du is the inverse of displacement rate
- Collapse times of two cases of landslides and a rock slope collapse were predicted by using a similar method at the error of 6 min., 5 hours and 20 min., respectively.