Slopeland Engineering

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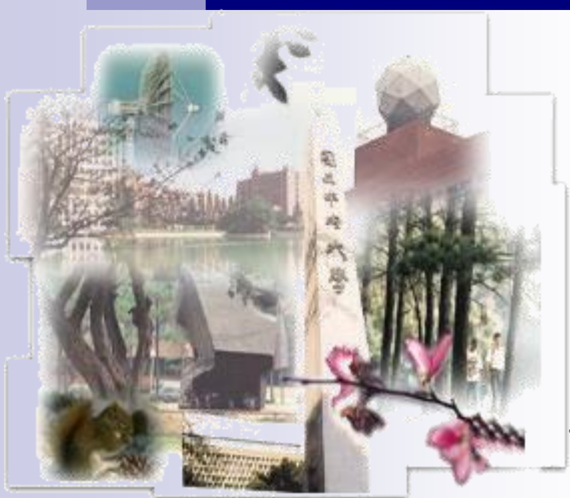


National Central University *Department of Civil Engineering*

Outline

1. **Introduction**
2. **Failure Types**

   To understand the development and form of natural slopes and the processes responsible for different natural features.
3. **The Causes of Landslide**
4. **Physical Modeling and Stability Analysis**

   To assess the stability of slopes under short-term (often during construction) and long-term conditions.
   To analyze landslides and to understand failure mechanisms and the influence of environmental factors.
5. **Countermeasures**

   To enable the redesign of failed slopes and the planning and design of preventive and remedial measures, where necessary.

Slope stability and stabilization methods

LEE W. ABRAMSON, THOMAS S. LEE, SUNIL SHARMA, GLENN M. BOYCE

1. Introduction

Pangaea

200 millions years ago

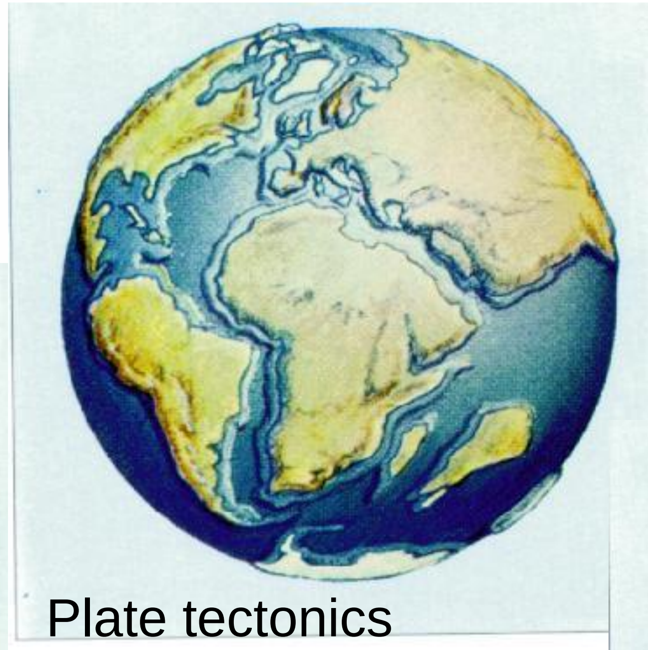
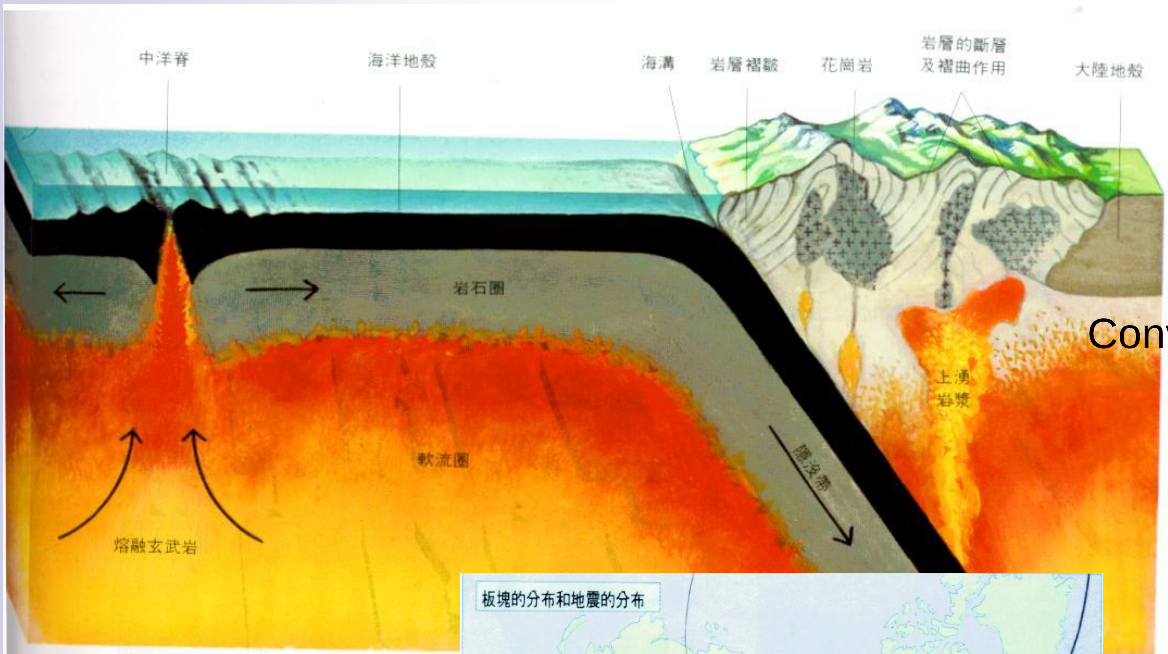


Plate tectonics

Current Days

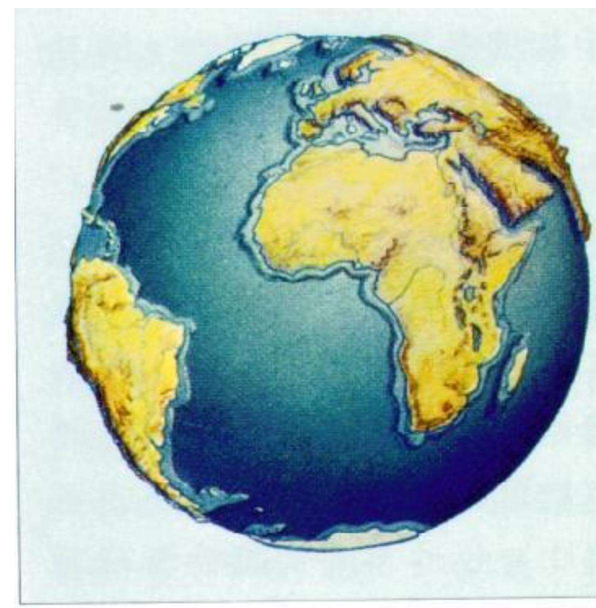
1. Introduction

Plate motion



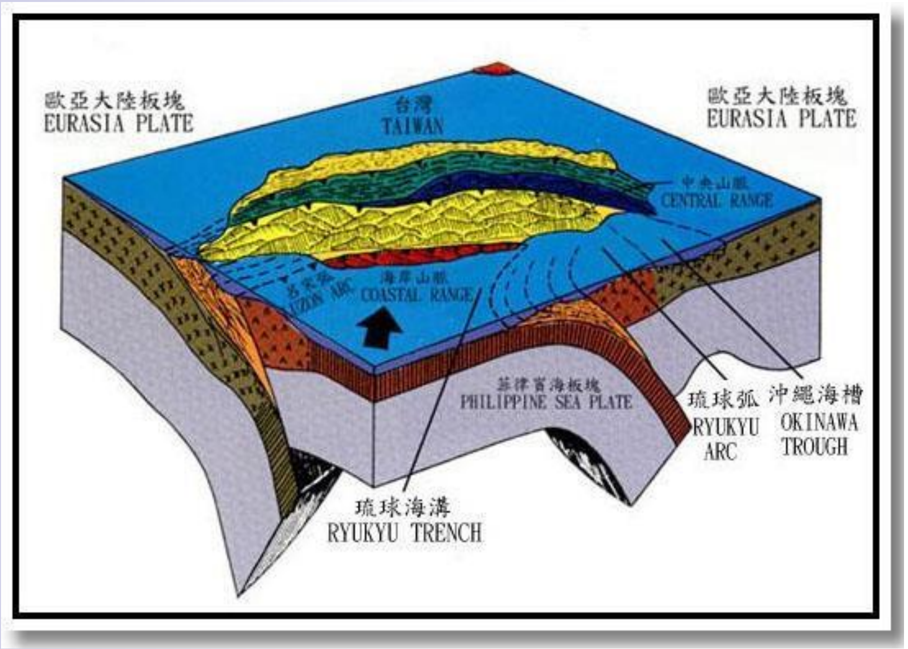
Convergent plate boundary

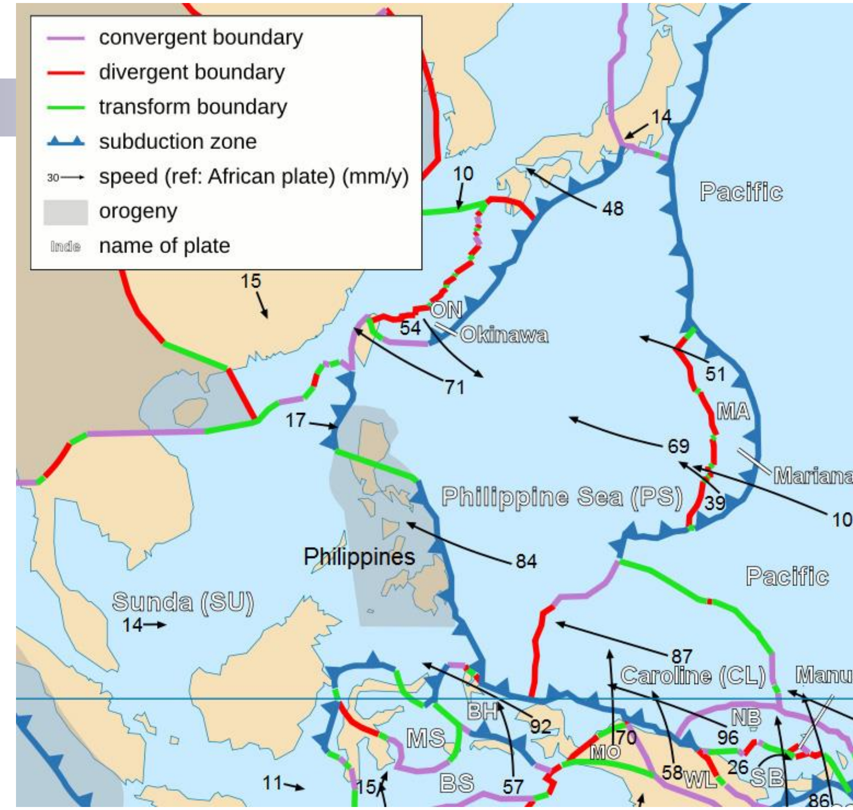
Divergent plate boundary



Circum-Pacific Seismic Zone

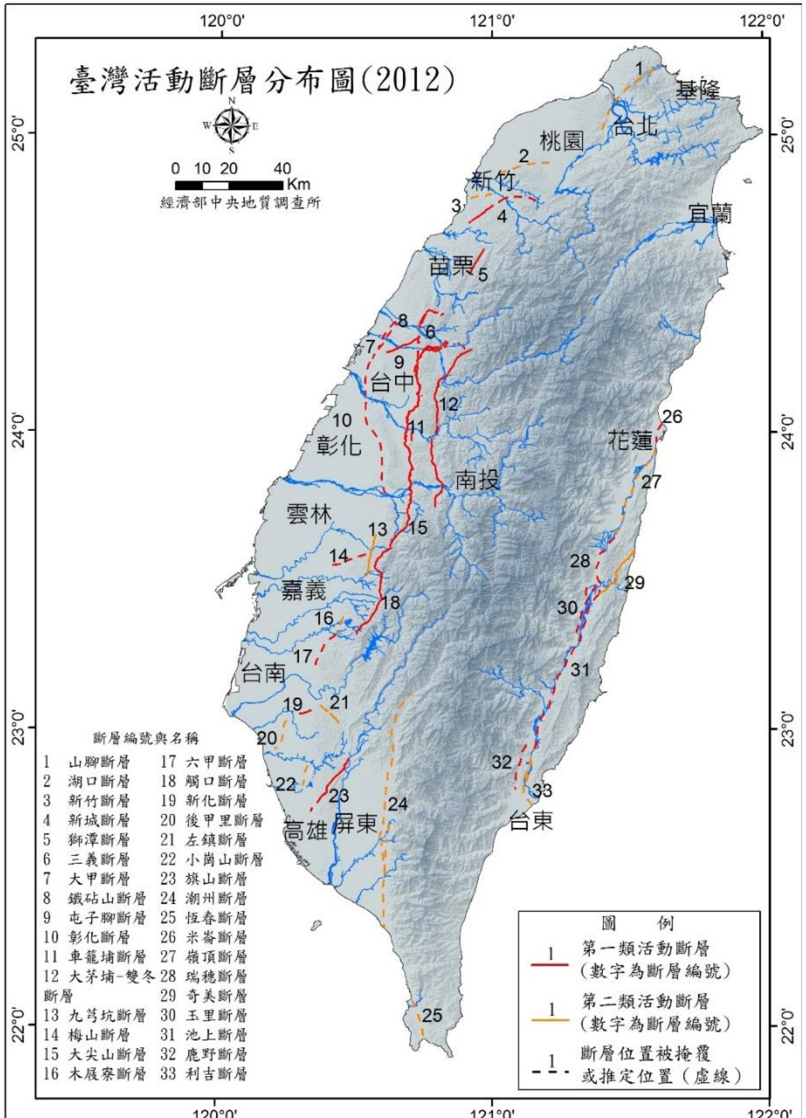
1. Introduction





The island of Taiwan was formed approximately 4 to 5 million years ago at a complex convergent boundary between the Philippine Sea Plate and the Eurasian Plate. In a boundary running the length of the island and continuing southwards in the Luzon Volcanic Arc (including Green Island and Orchid Island), the Eurasian Plate is sliding under the Philippine Sea Plate.

1. Introduction

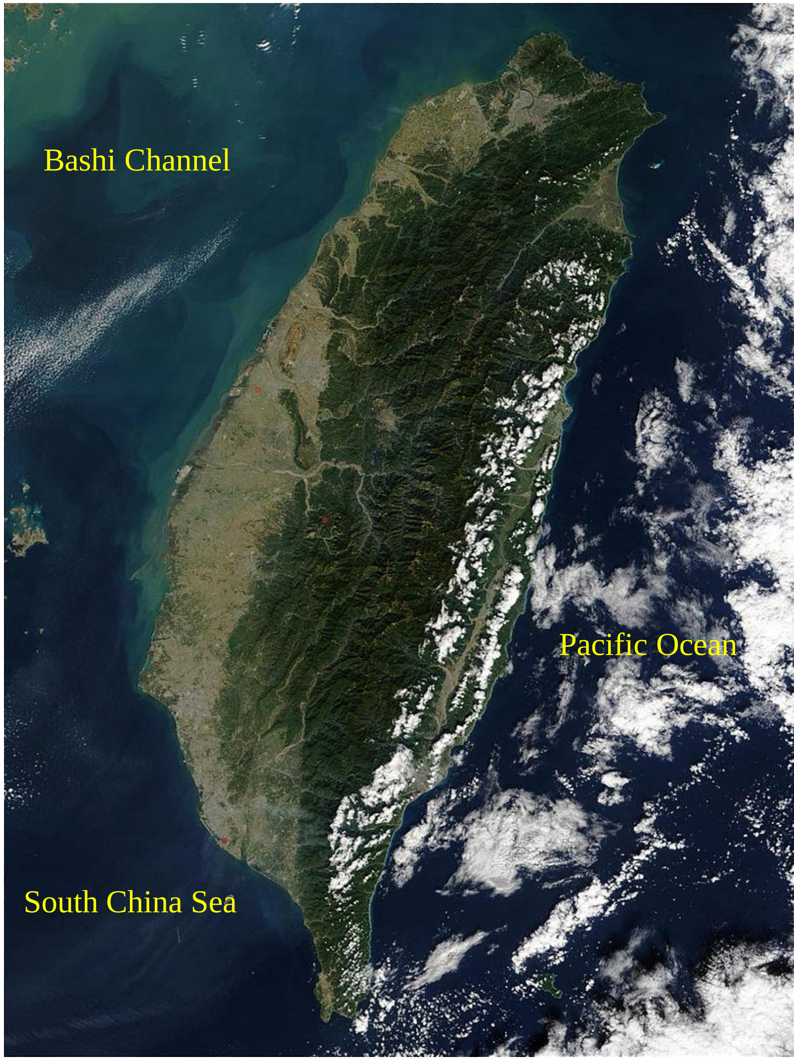


1. Introduction

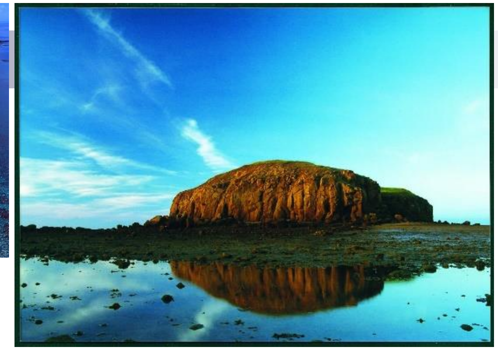
NS-Length: 395 km
WE-Width: 144km
Length of coast: 1139 km
Area: 35883 km^2
(It is smaller than Switzerland and larger than Belgium.)

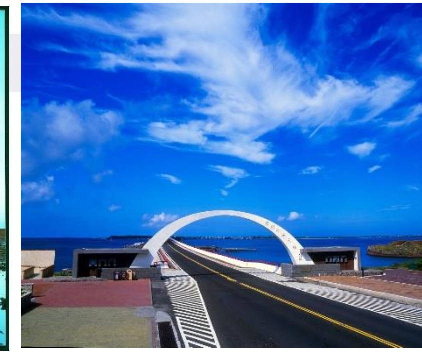
The Penghu Islands are west of the main island.

The shape of the main island of Taiwan is similar to a sweet potato seen in a south-to-north direction



1. Introduction





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WE-Width: 144km
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(It is smaller than Switzerland and larger than Belgium.)

The Penghu Islands are west of the main island.

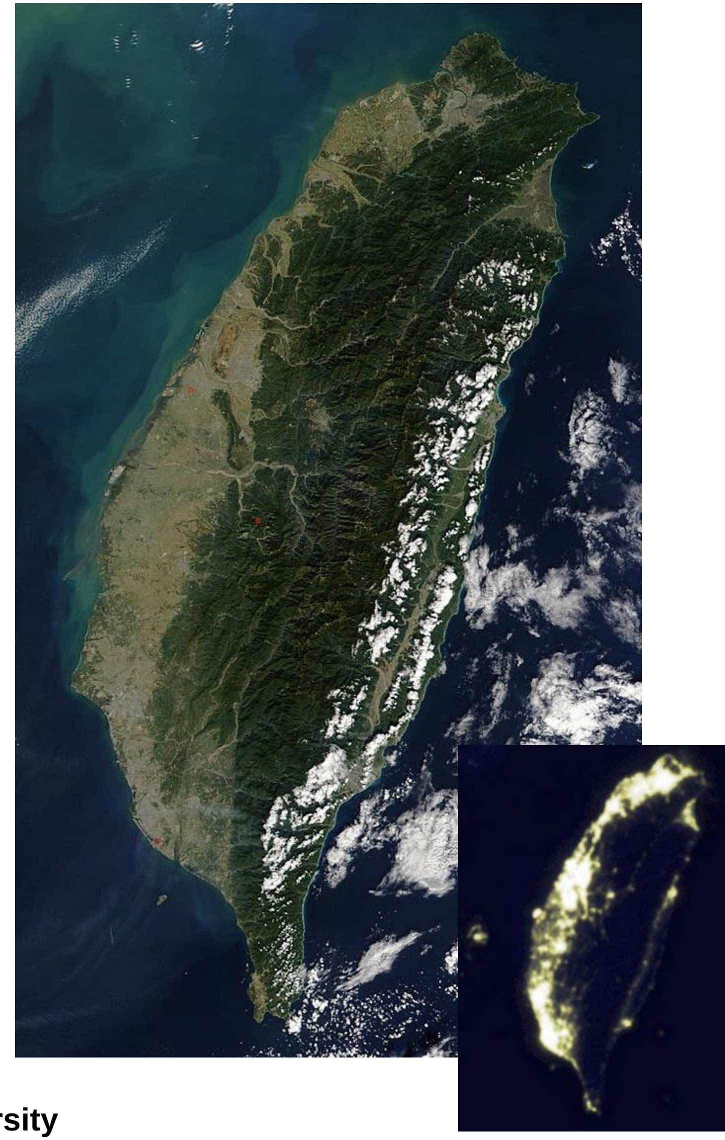
1. Introduction

The terrain in Taiwan is divided into two parts:

1. The flat to gently rolling plains in the west and occupied one-third of Taiwan. (90% of the population lives)
2. The mostly rugged forest-covered mountains in the eastern and occupied about two-thirds of Taiwan.

The eastern part of the island is dominated by five mountain ranges which arrange from north-northeast to south-southwest, roughly parallel to the east coast of the island. As a group, they extend 330 km from north to south and average about 80 km from east to west. There are 269 peaks with elevations of over 3000 m.

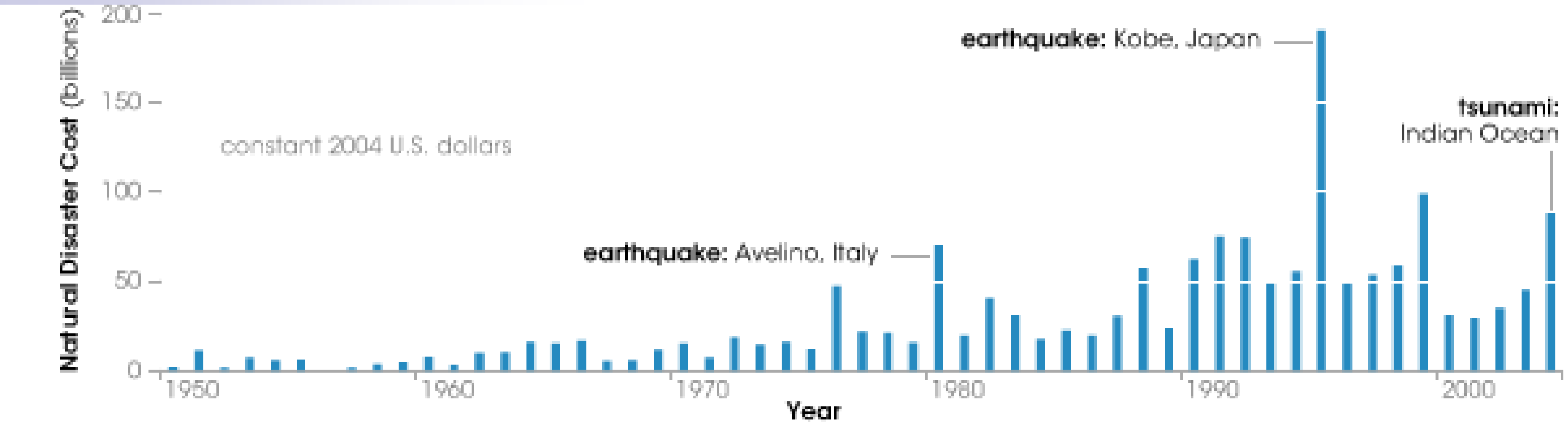
(38 peaks with elevations between 2900 m to 3000 m)



1. Introduction

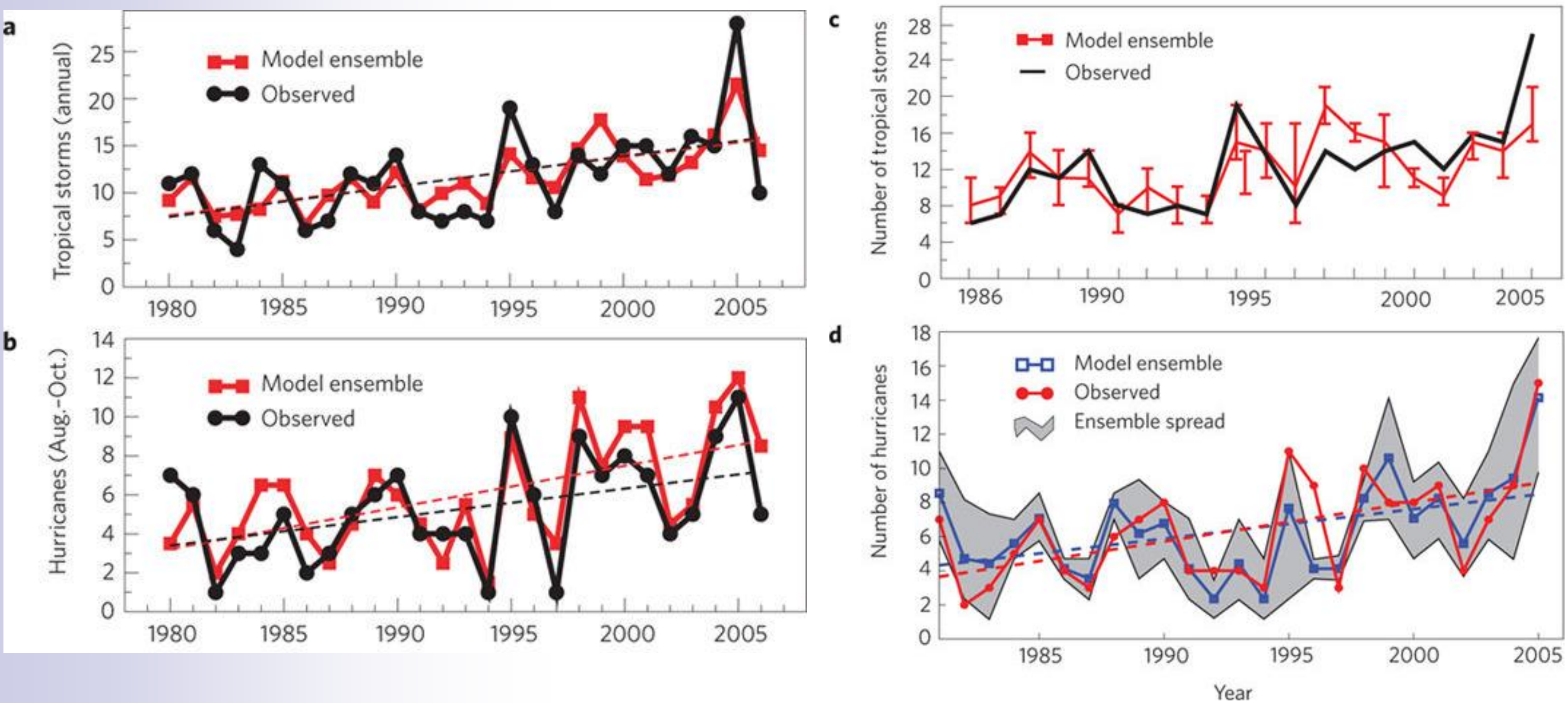
1. Introduction

We need to pay more to recover



The OFDA/CRED International Disaster Database (www.em-dat.net) Université Catholique de Louvain—Brussels, Belgium)

1. Introduction

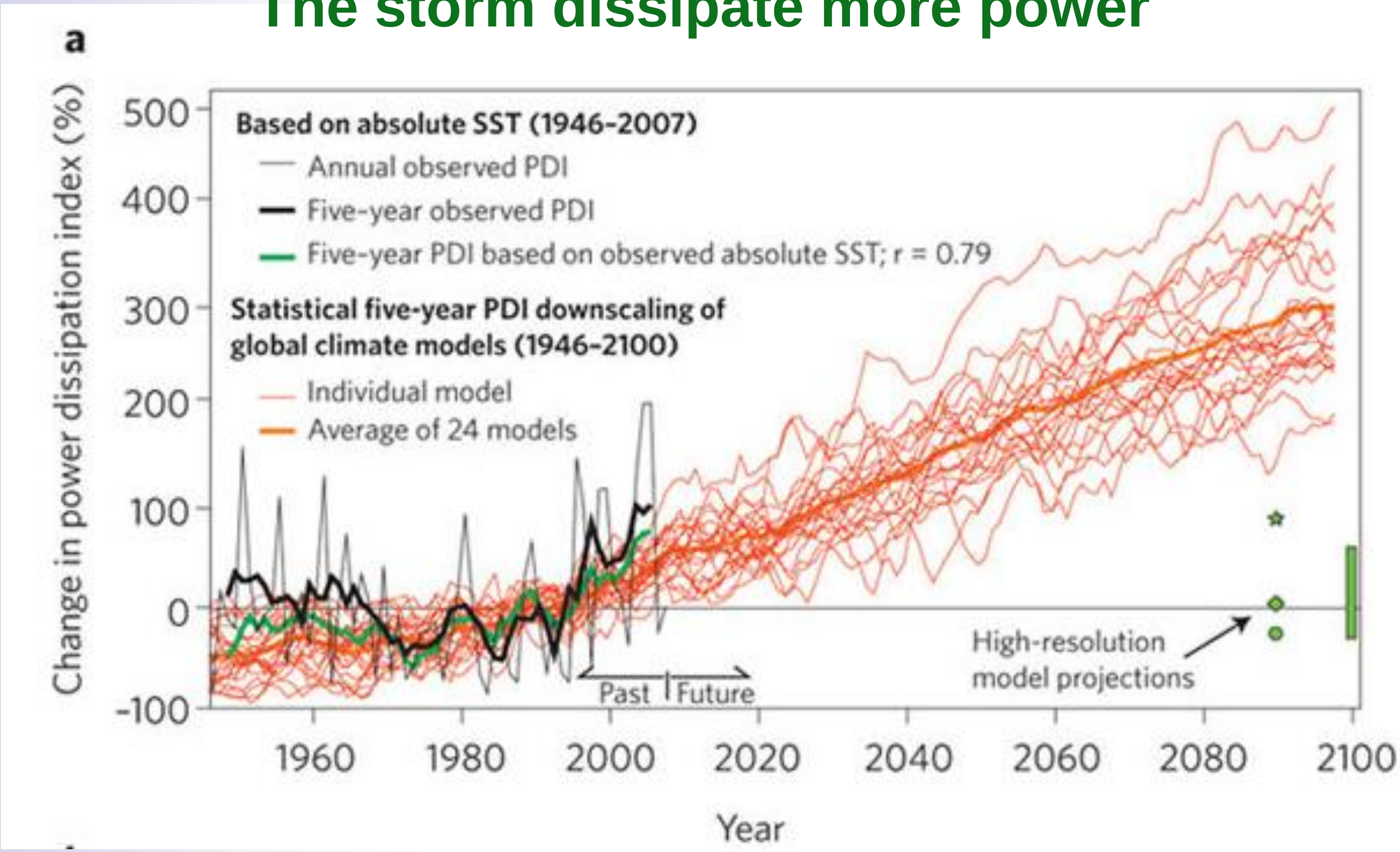


We have to subjected to more hurricanes/ tropical storm

Thomas R. Knutson (2010) – Nature Geoscience

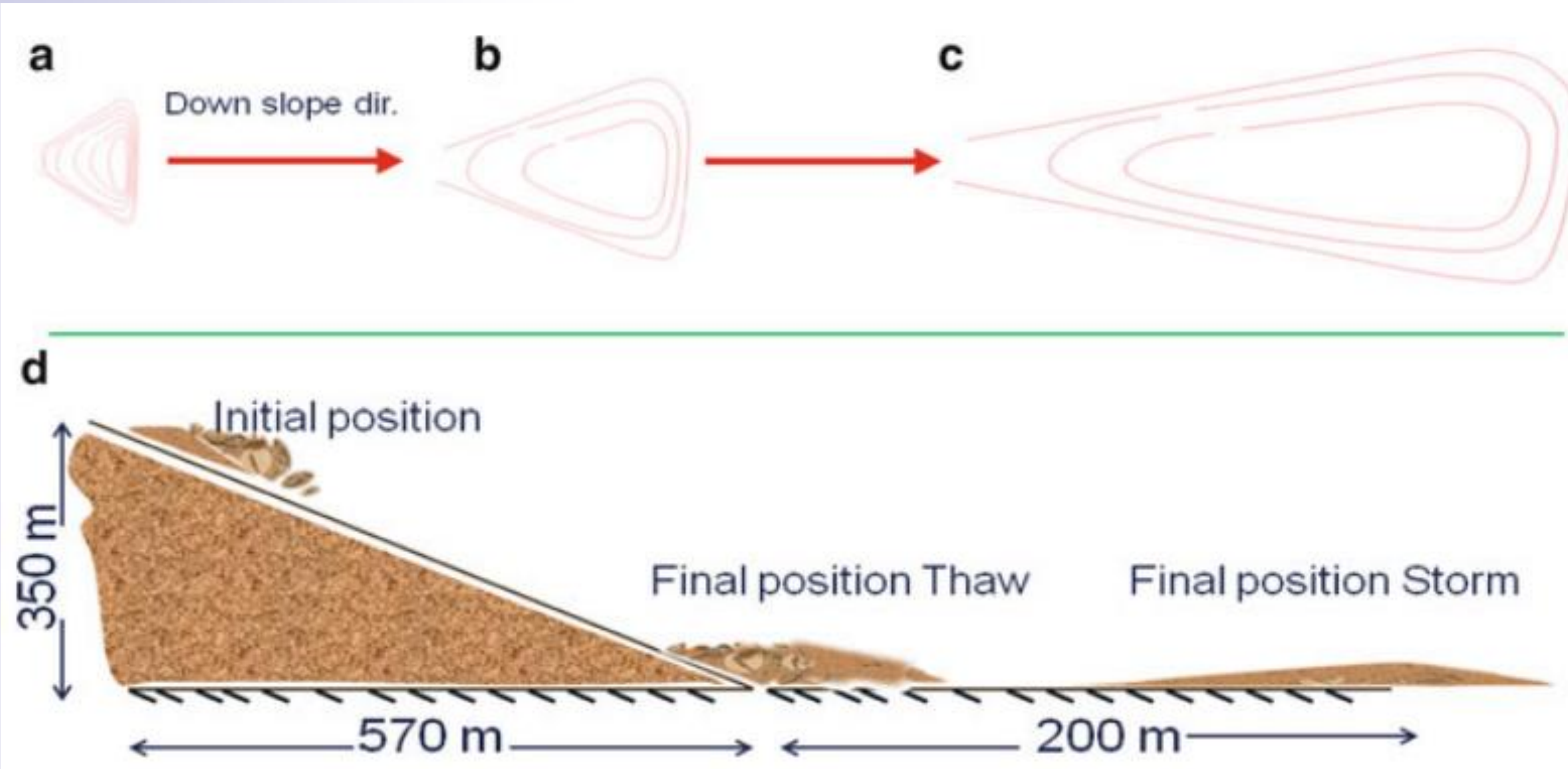
1. Introduction

The storm dissipate more power



Thomas R. Knutson (2010) – Nature Geoscience

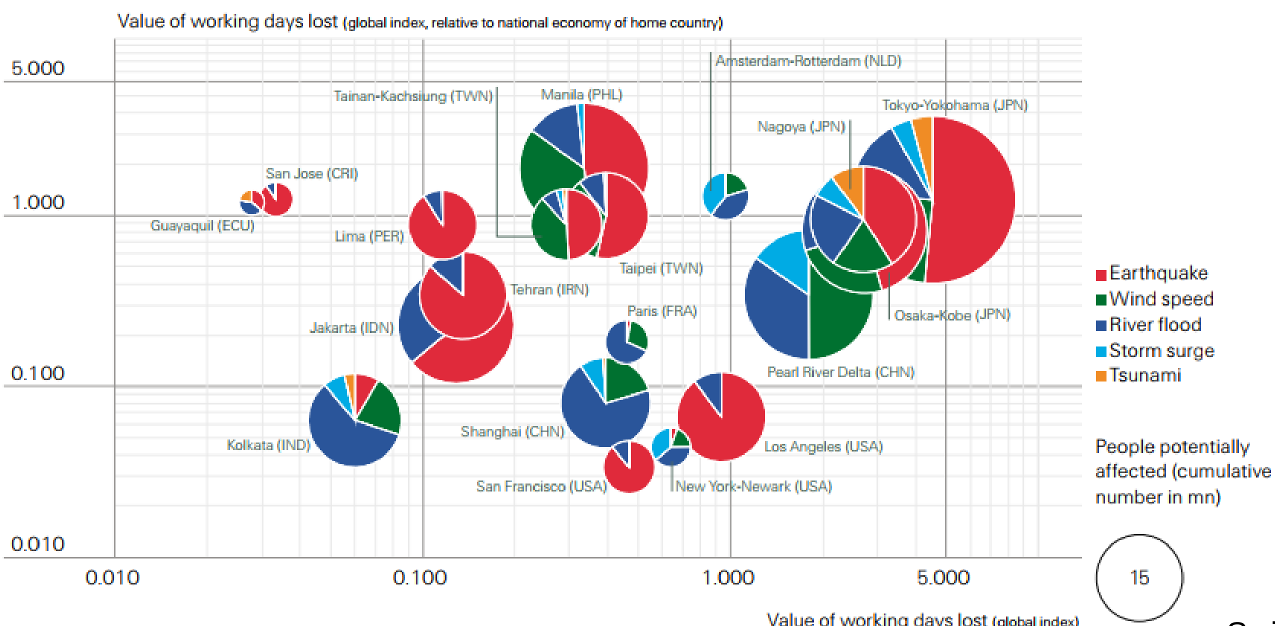
1. Introduction



Diandong Ren – Storm triggered Landslide in warmer climate (2015)

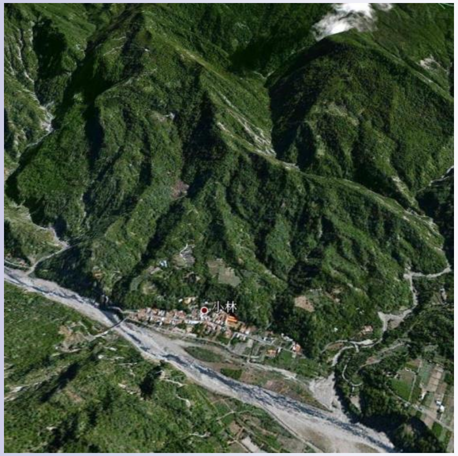
1. Introduction

Taiwan has two city highly vulnerable to the natural disaster. The disasters also have critical impact to country's economic

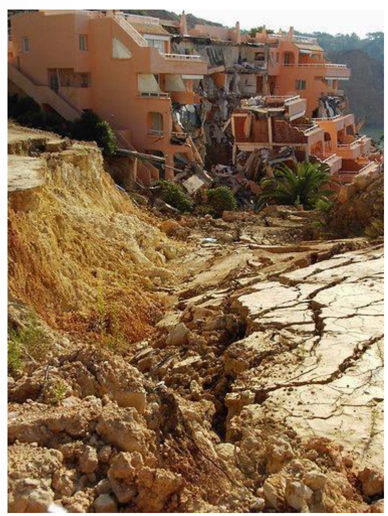


Metro area	Ranking: value of working days lost relative to national economy (global index, aggregated for all 5 perils)
Manila (PHL)	1.95
Amsterdam-Rotterdam (NLD)	1.31
Tokyo-Yokohama (JPN)	1.29
San Jose (CRI)	1.26
Guayaquil (ECU)	1.20
Taipei (TWN)	1.02
Ndjamena (TCL)	1.00
Nagoya (JPN)	0.97
Tainan-Kaohsiung (TWN)	0.90
Lima (PER)	0.90

Swiss Reinsurance Company - 2014



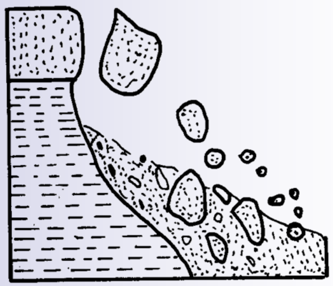
2. Failure Types



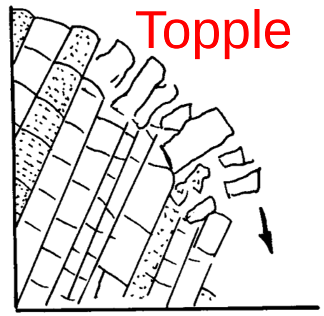
2. Failure Types

Fall

(A)



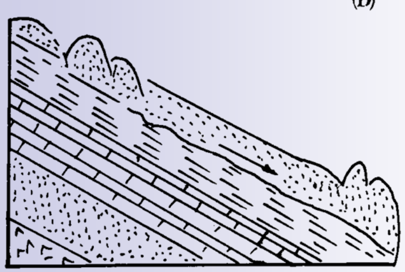
(B)



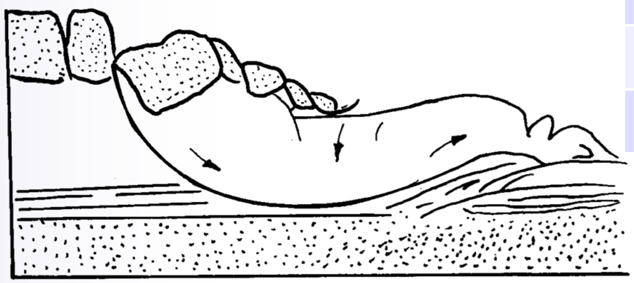
Topple

Class	Description	Velocity (mm/sec)
7	Extremely rapid	5×10^3
6	Very Rapid	50
5	Rapid	0.5
4	Moderate	5×10^{-3}
3	slow	5×10^{-3}
2	Very slow	5×10^{-3}
1	Extremely slow	

(C)

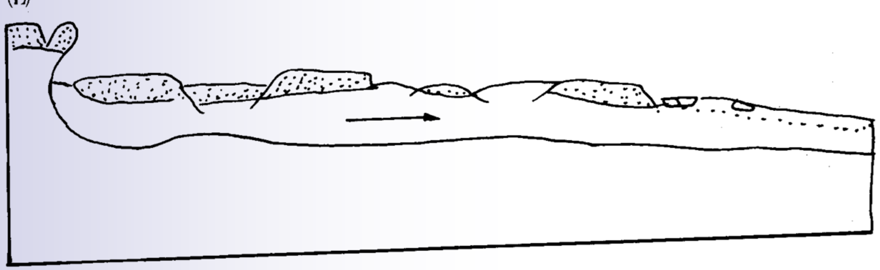


(D)

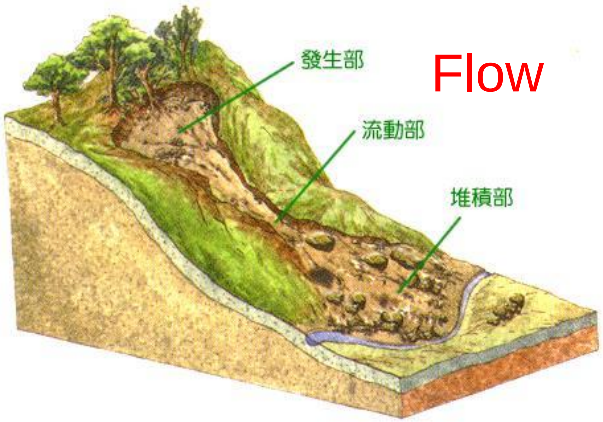


Slide

(E)

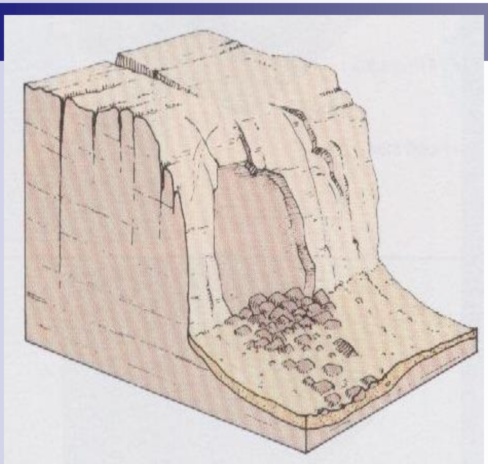


Spread



Flow

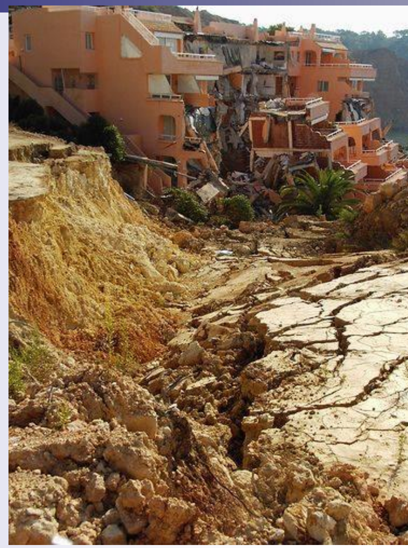
2. Failure Types- Rock Fall



2. Failure Types- Toppling

Topple

2. Failure Types- Sallow Slide



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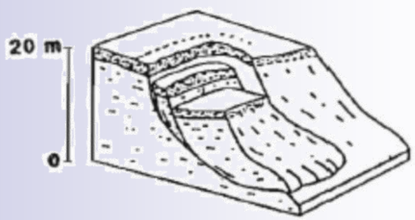
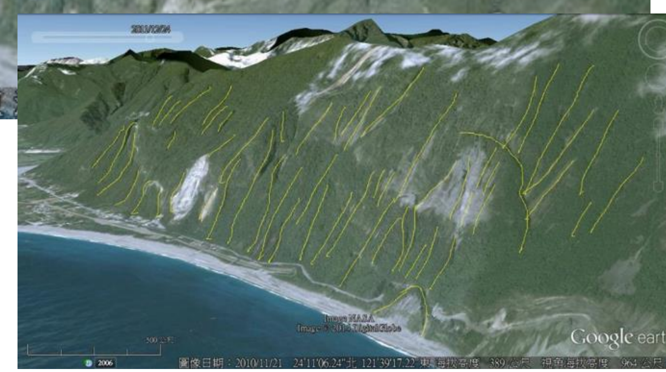


Slide

2. Failure Types- Release joints



Mountain at east Taiwan
(Pressure release joints)

2. Failure Types- Release Joints

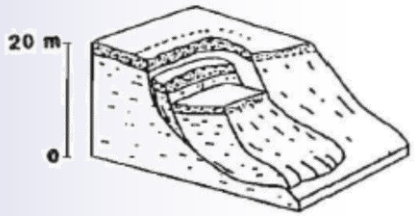
East coast of Taiwan

2. Failure Types- Release Joints

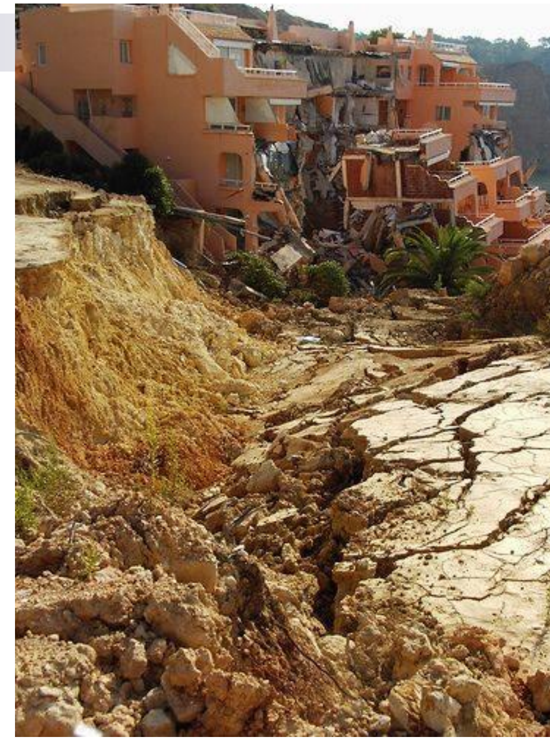
Road along the east coast of Taiwan

2. Failure Types- Deep Slide

3



Slide



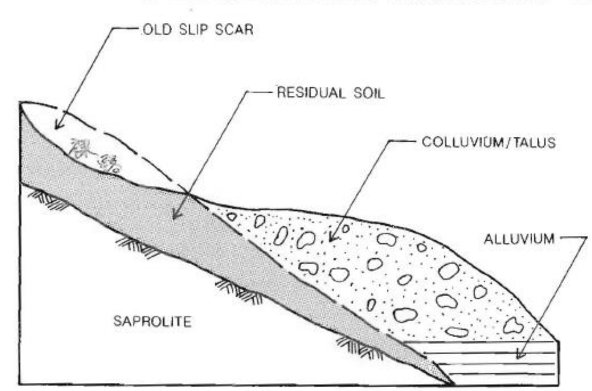
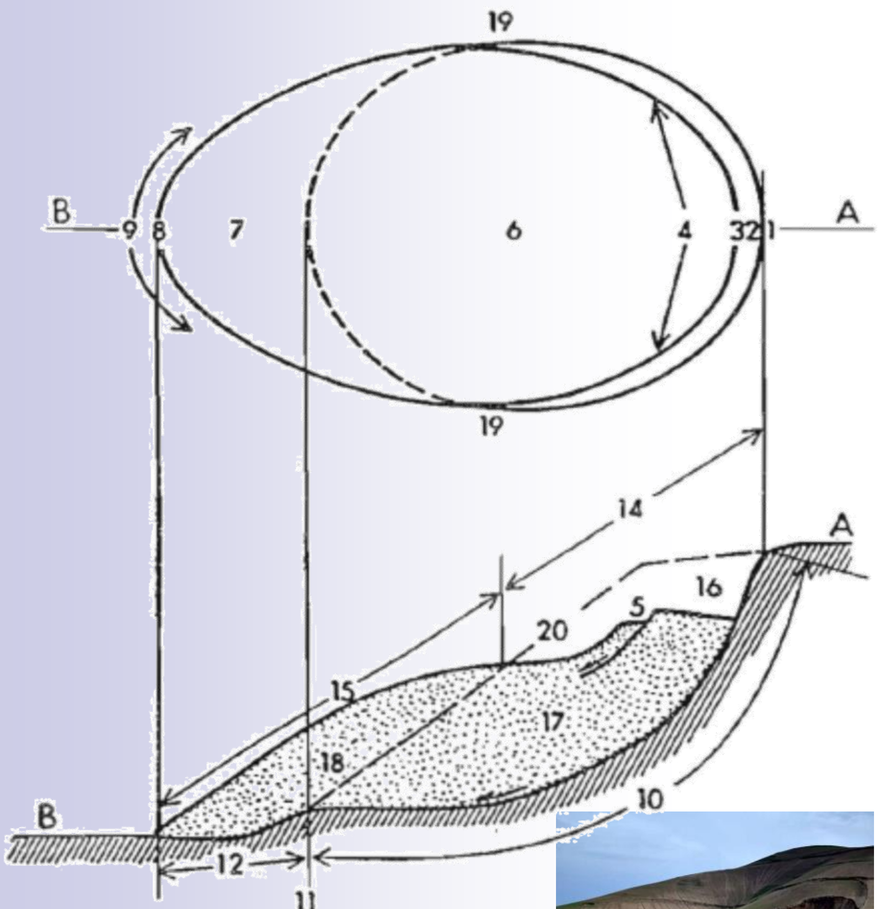


Figure 2.5 Colluvial/talus deposits moving downslope.

2. Failure Types- Deep Slide



(1) *Crown* 冠部
The practically undisclosed material above the main scarp
(2) ***Main Scarp*** **主崖**
A steep surface on the undisturbed ground at the upper edge of the landslide
(3) ***Top*** **頂部**
The highest point of contact between the displaced material and main scarp
(4) ***Head*** **頭部**
The upper parts of the landslide between the displaced material and main scarp
(5) ***Miner Scarp*** **小崖**
A steep surface on the displaced material produced by differential movements
(6) ***Main Body*** **主體**
The part of the displaced material that overlies the surface of rupture
(7) ***Foot*** **足部**
The portion of the landslide that has moved beyond the toe

Slope stability and stabilization methods
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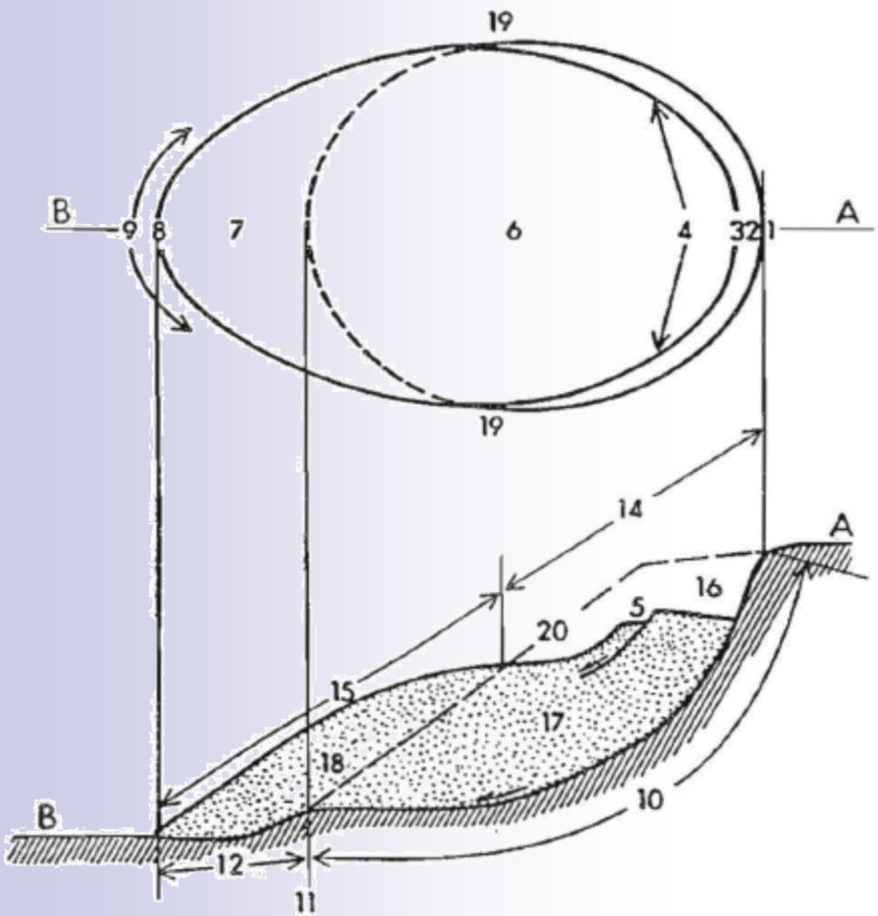
2. Failure Types- Deep Slide



(8) ***Tip* 尖部**
The point on the toe farthest from the top
(9) ***Toe* 趾部**
The lower margin of the displaced material
(10) ***Surface of Rupture* 滑動面**
The surface that forms the lower boundary of the displaced material
(11) ***Toe of Surface of Rupture* 滑動面趾部**
The interaction between the lower part of the rupture surface and the original ground surface
(12) ***Surface of Separation* 分離面**
The original ground surface now overlain by the foot of the landslide
(13) ***Displaced Material* 滑動料**
Material displaced from its original position by landslide movement

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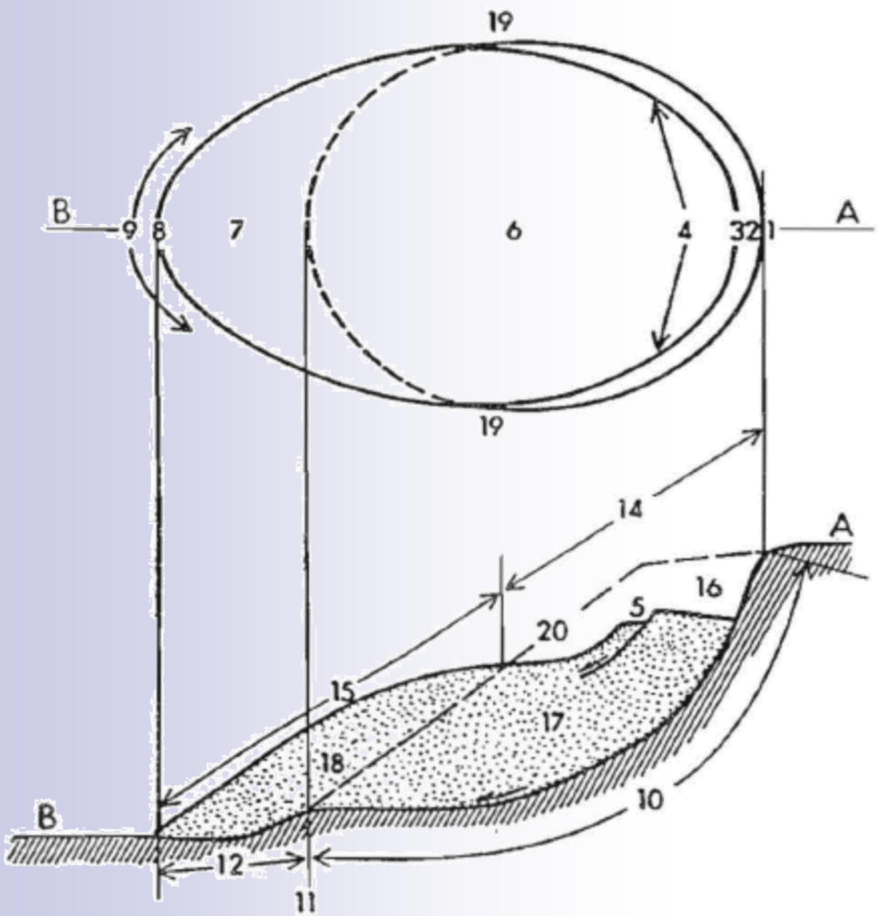
2. Failure Types- Deep Slide



(14) **Zone of Depletion 消耗區**
The area within which the displaced material lies below the original ground surface

(15) **Zone of Accumulation 堆積區**
The area within which the displaced material lies above original ground surface

(16) **Depletion 消耗體積**
The volume bounded by the main scarp, the depleted mass, and the original ground surface

(17) **Depletion Mass 消耗體**
The volume of displaced material that overlies the rupture surface but underlies the original ground surface

(18) **Accumulation 堆積體**
The volume of the displaced material that lies above the original ground surface

(19) **Flank 側翼**
The undisclosed material adjacent to the sides of the rupture surface

(20) **Original Ground Surface 原地表面**
The surface of the slope that existed before the landslide took place

Slope stability and stabilization methods
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2. Failure Types- Deep Slide

(1) Width of Displaced Mass, W_d 滑動體寬度
The maximum breadth of the displaced mass perpendicular to the length, L_d

(2) Width of the Rupture Surface, W_r 滑動面寬度
The maximum width between the flanks of the landslide, perpendicular to the length, L_r

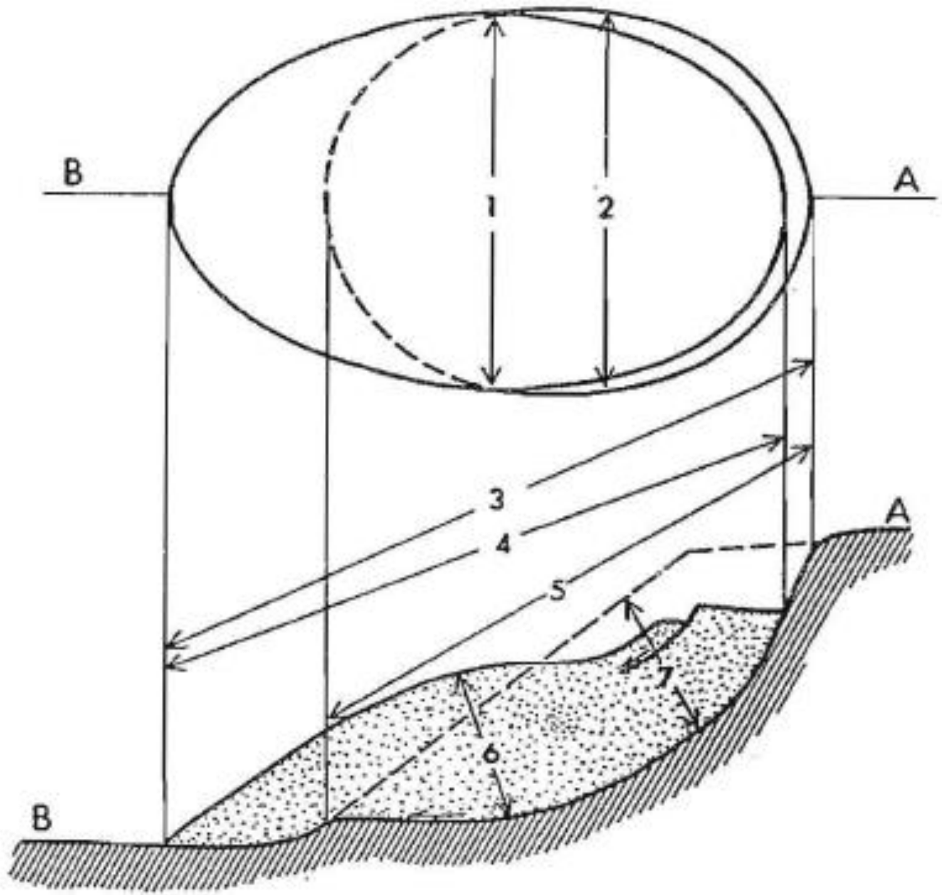
(3) Total Length, L 總長度
The minimum distance from the tip of the landslide to its crown

(4) Length of Displaced Mass, L_d 滑動體長度
The minimum distance from tip to the top

(5) Length of the Rupture Surface, L_r 滑動面長度
The minimum distance from the toe of the surface of rupture to the crown

(6) Depth of the Displaced Mass, D_d 滑動體深度
The maximum depth of the displaced mass, measured perpendicular to the plane containing W_d and L_d

(7) Depth of the Rupture Surface, D_r 滑動面深度
The maximum depth of the rupture surface below the original ground surface measured perpendicular to the plane containing W_r and L_r



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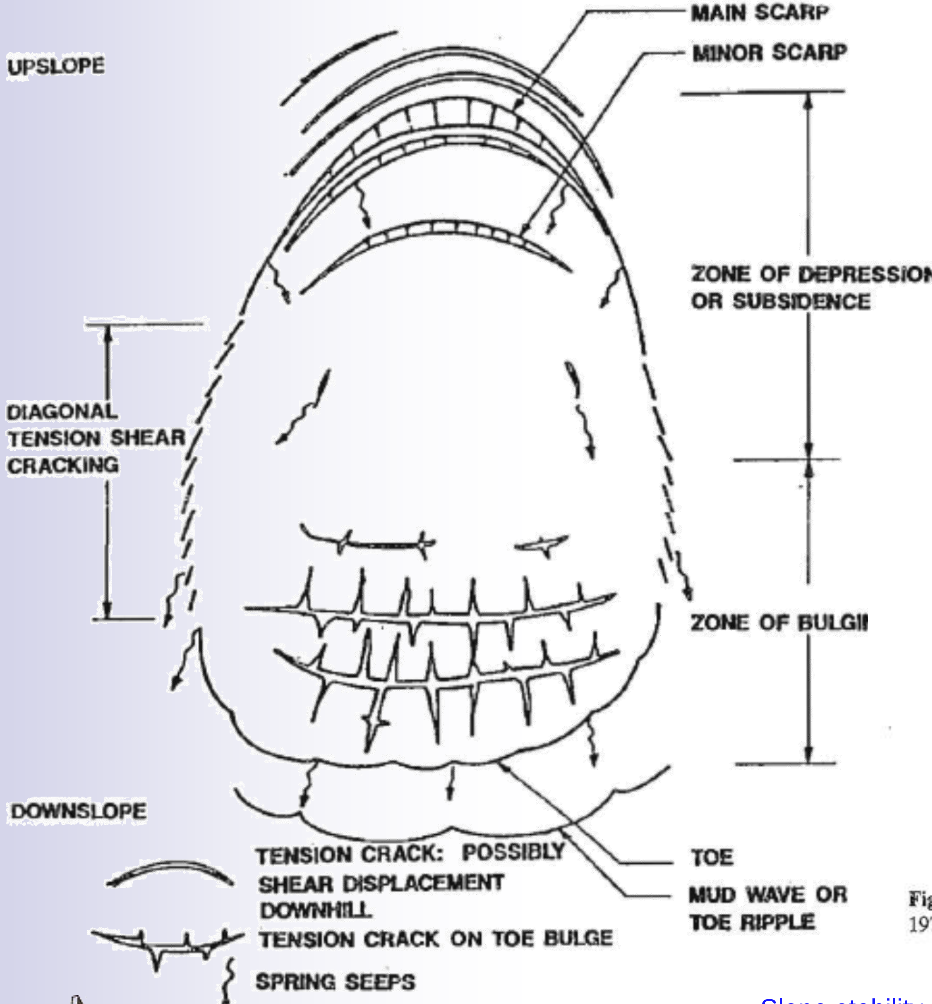
2. Failure Types- Deep Slide



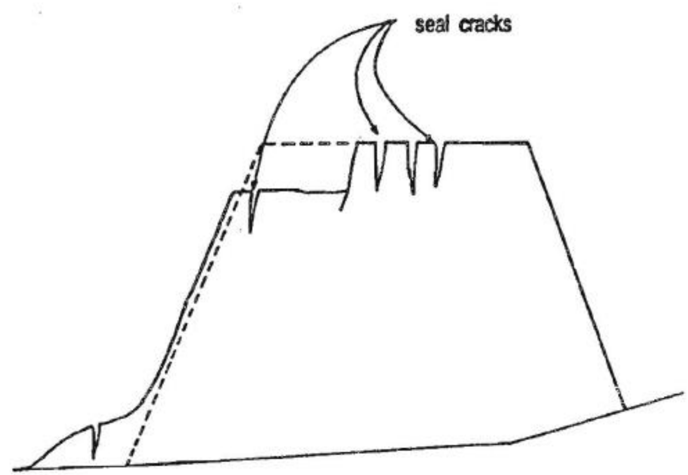


Figure 2.17 Development of escarpment in or above a roadway.

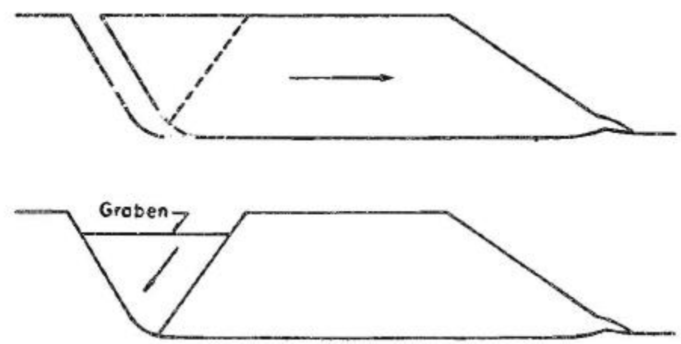


Figure 2.13 Mechanism of graben formation due to sliding on horizontal layer (Seed, 1970a).

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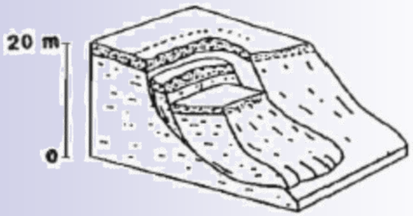
2. Failure Types- Deep Slide

3

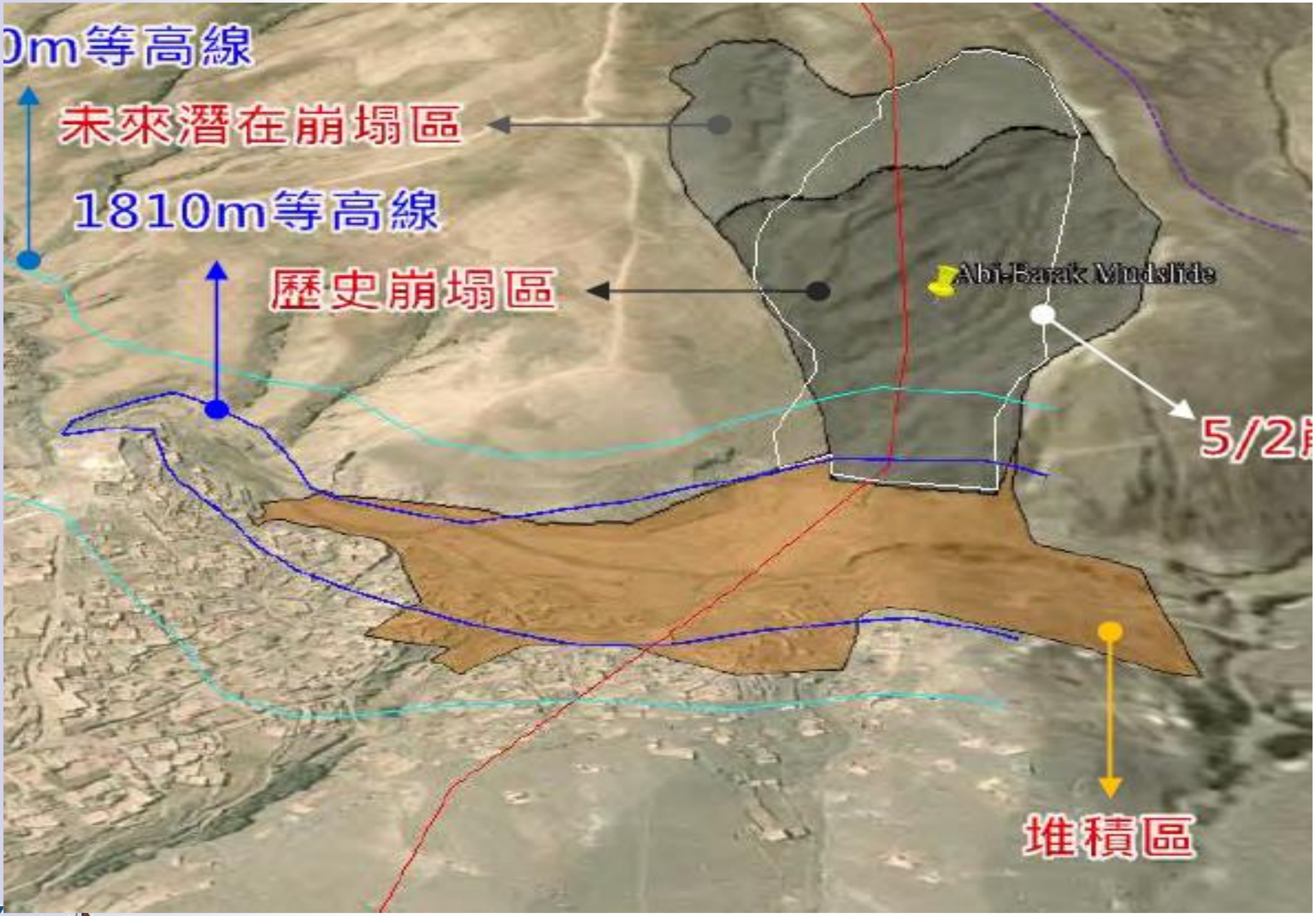


Slide

Afghan Landslide

2014/5/2(Fri), 12:00(1st), 14:00(2nd).

2. Failure Types- Deep Slide



2. Failure Types- Deep Slide

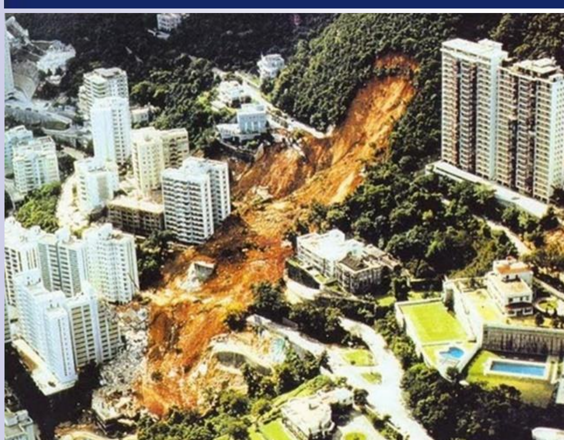
2. Failure Types- Deep Slide at Highway

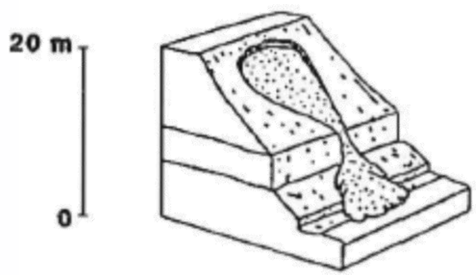
2. Failure Types- Deep Slide at Residential Area

2. Failure Types- Deep Slide at Residential Area

Residential area located at dip slope slopeland

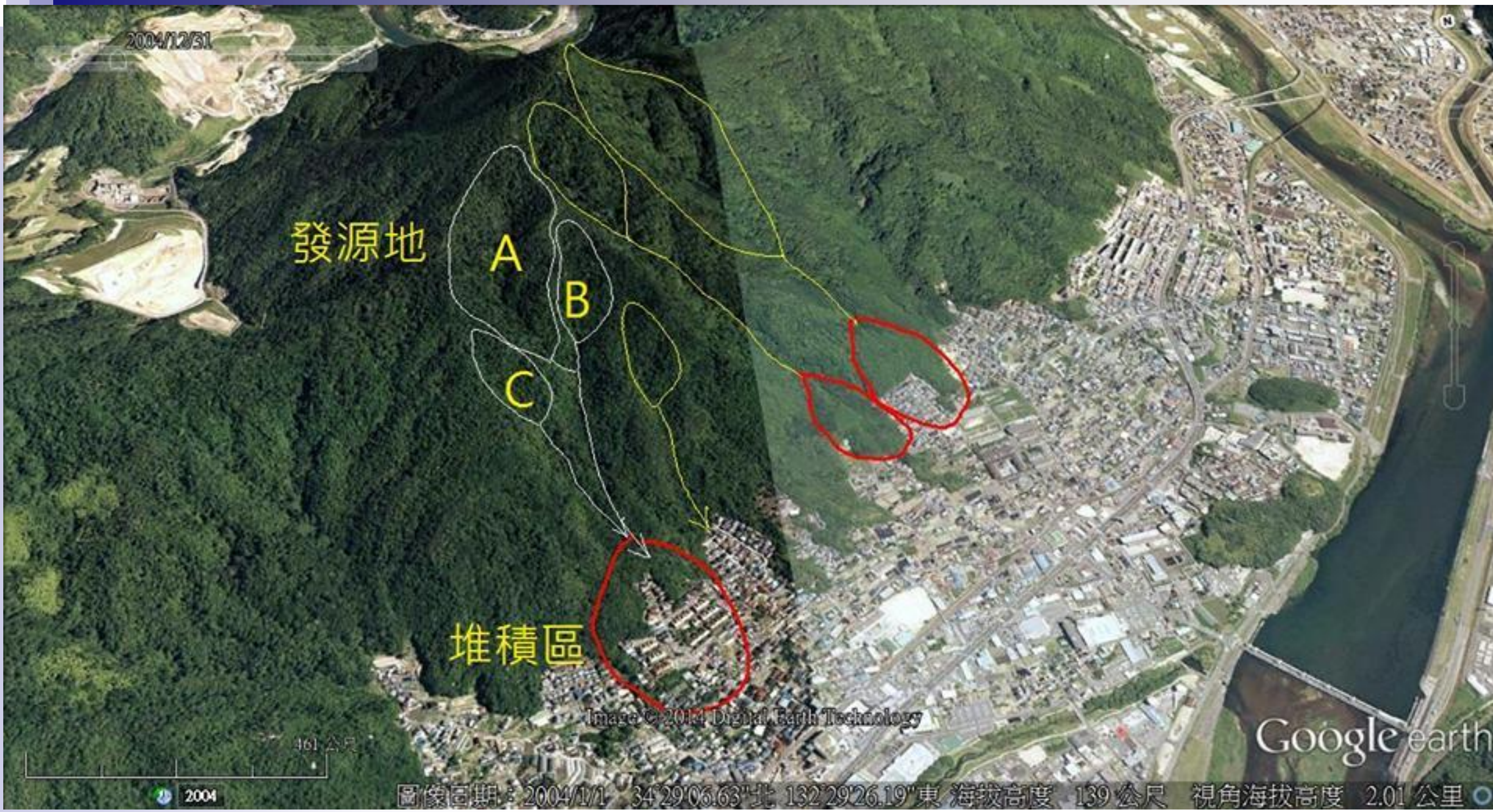
2. Failure Types- Flow





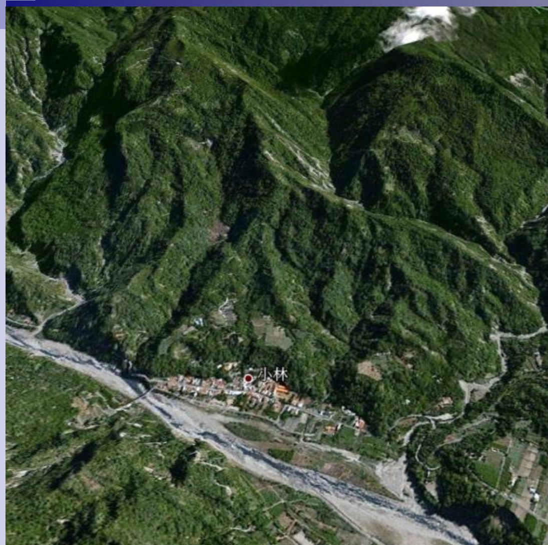
Flow (Hong Kong, 1972)

2. Failure Types- Complex Disaster



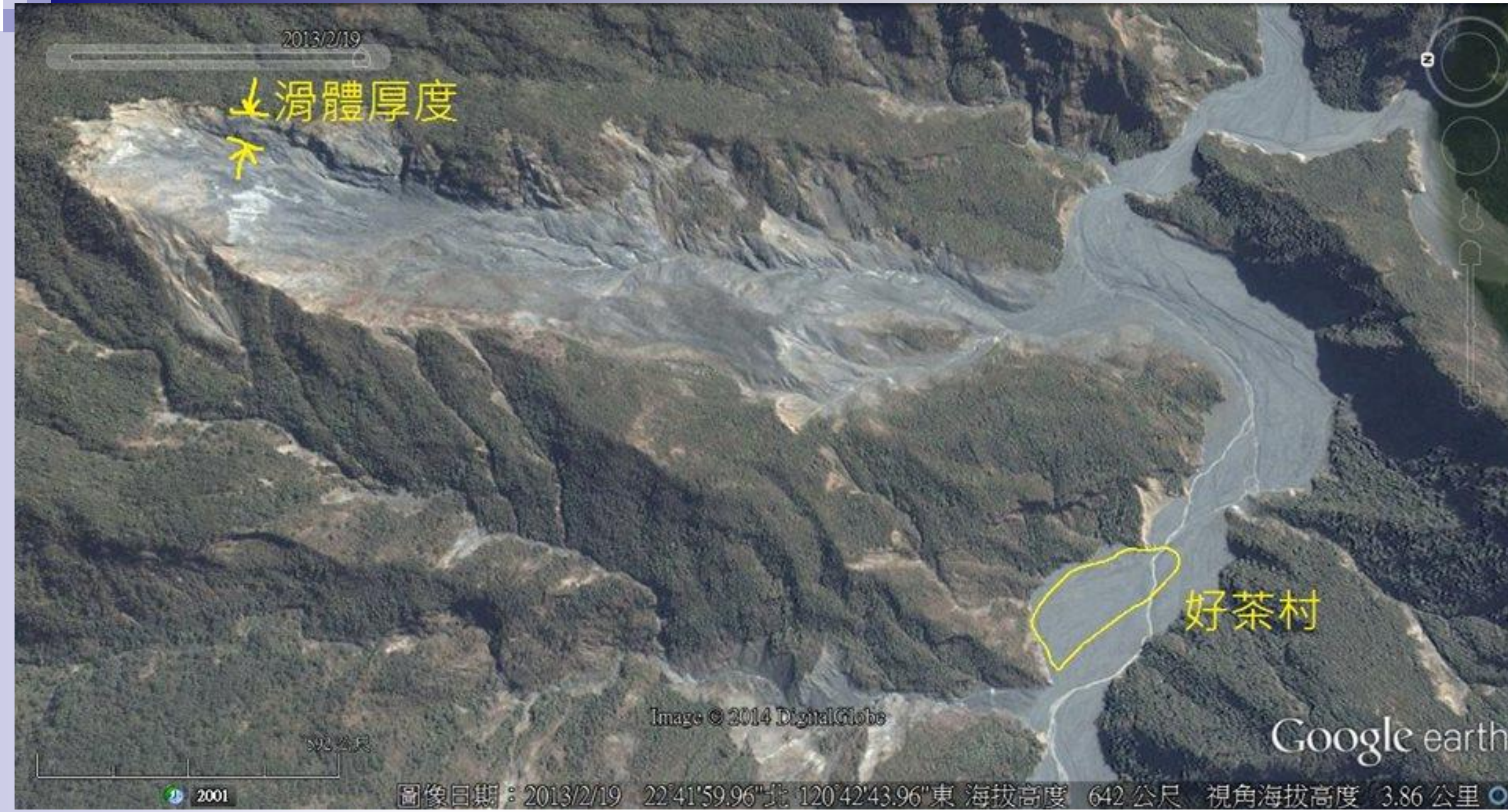
Hiroshima, Japan (2014.08.20)

2. Failure Types- Complex Disaster



Colluvium + Heavy rainfall
Slide + Dammed lake

2. Failure Types- Complex Disaster



Infiltration caused deep landslide

3. The Causes of Landslide

3. The Causes of Landslide- River System

River system caused landslide
(Back erosion to the upstream of river)

3. The Causes of Landslide- River System

River system caused landslide

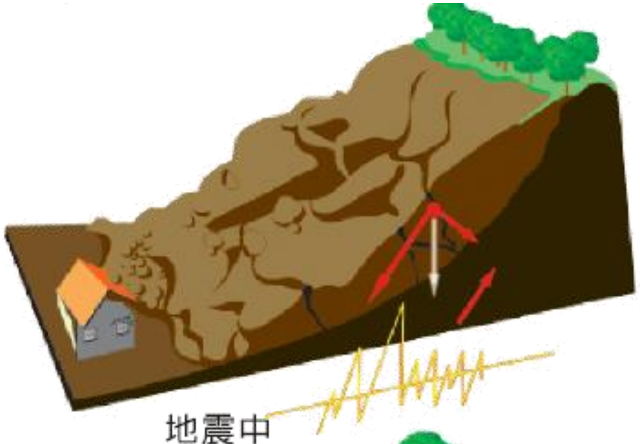
3. The Causes of Landslide- Gravity

Gravity caused large landslide

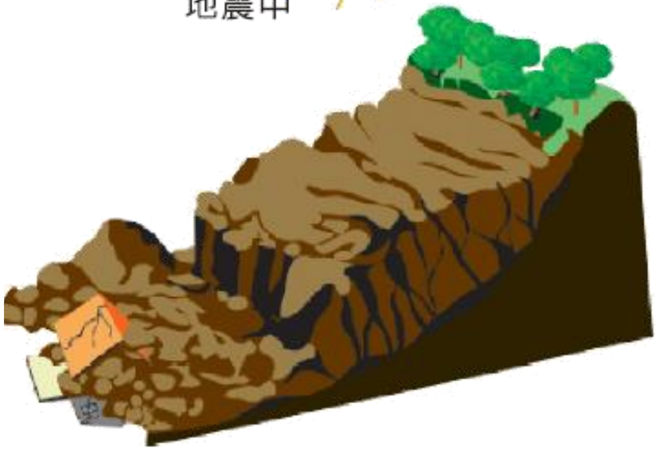
3. The Causes of Landslide- Earthquake

Earthquake caused landslide (Chi-Chi Earthquake,1999/9/21)

3. The Causes of Landslide- Earthquake



The soil mass moves during shaking.



Structures are destroyed by landslide.

3. The Causes of Landslide- Erosion

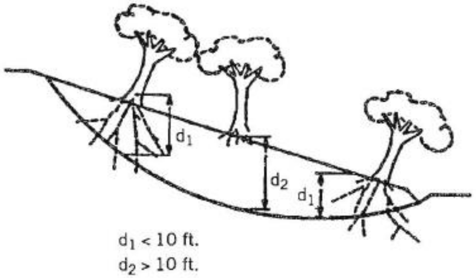
Back erosion and cut the ground of plateau

3. The Causes of Landslide

Gentle slope ▸ Safety??

It depends on the properties of materials. Sometime, a weak layer is sandwiched between two rock layers.

3. Evidence for Landslide



Evidence of landslide in the past

3. Evidence for Landslide

Evidence of slow-deep landslide

3. Evidence for Landslide

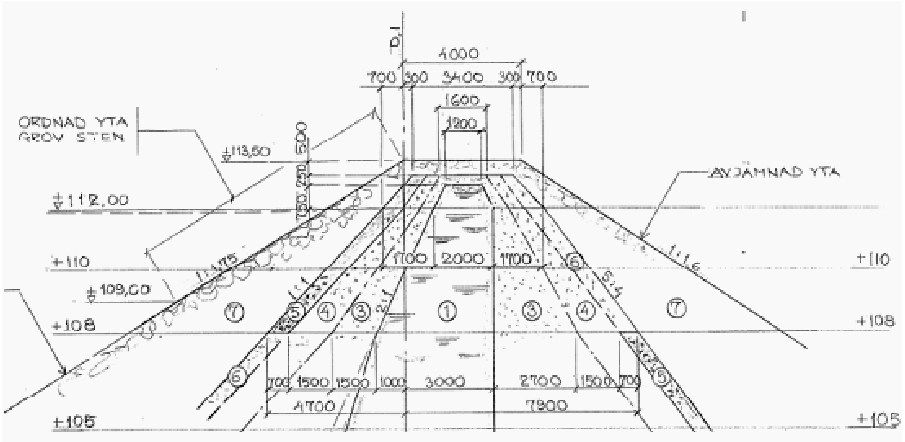


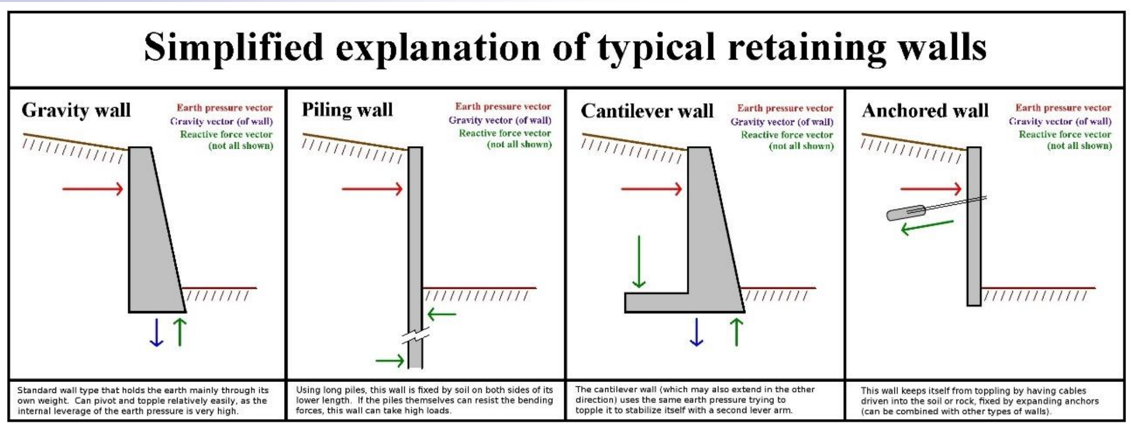
4. Physical Modeling and Stability Analysis

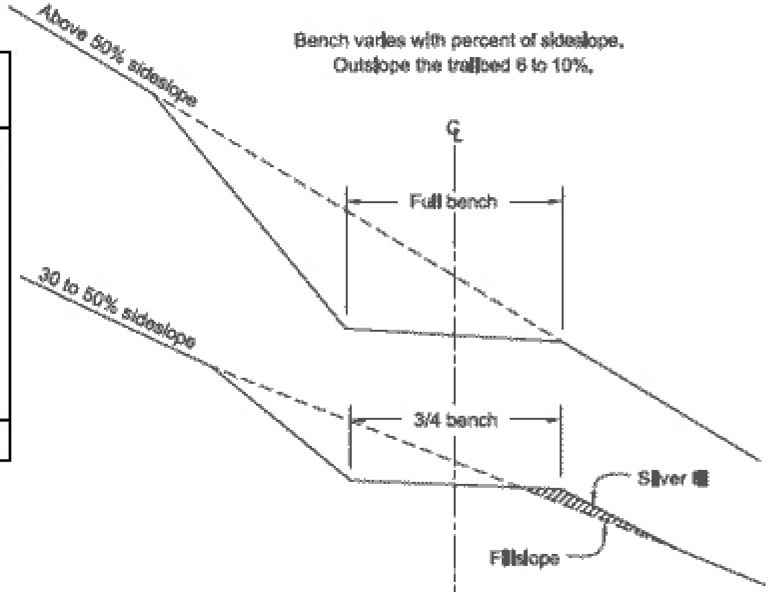
4. Physical Modeling and Stability Analysis

Engineered slopes may be considered in three main categories:

- Embankments
- Cut slopes
- Retaining walls.

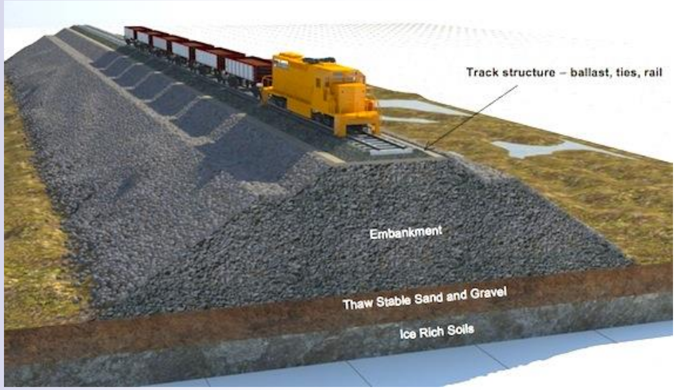


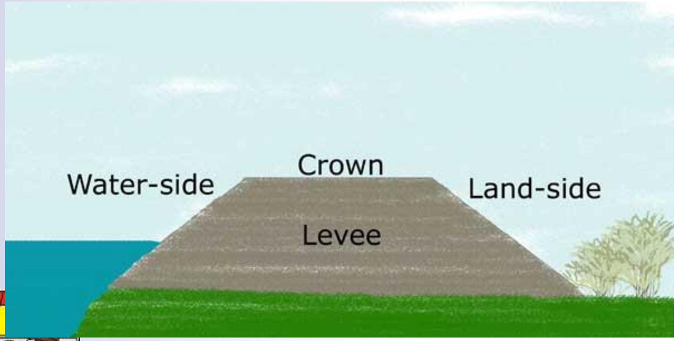




4. Physical Modeling and Stability Analysis

- Fill slopes involving compacted soils include highway and railway embankments, landfills, earth dams, and levees. The engineering properties of materials used in these structures are controlled by the borrow source grain size distribution, the methods of construction, and the degree of compaction.





4. Physical Modeling and Stability Analysis

Factors that cause increases in shear stresses in slope:

- Removal of support
  - Erosion
    - By streams, rivers and glaciers
    - By action of waves or marine currents
    - By successive wetting and drying
  - Natural slope movement
  - Human activity
    - Cuts and excavations
    - Removal of retaining walls or sheet piles
    - Drawdown of bodies of water
- Overloading
  - By natural causes
    - Weight of precipitation
    - Accumulation of materials because of past landslides
  - By human activity
    - Construction of fill
    - Buildings and other overloads at the crest
    - Water leakage in culverts, water pipes and sewers
- Transitory effects
- Removal of underlying materials that provided support
  - By rivers or seas, weathering, underground erosion due to seepage
  - By human activity (excavation or mining)
  - By loss of strength of the underlying material
- Increase in lateral pressure
  - By water in cracks and fissures, expansion of clays
  - By freezing of the water in the cracks

4. Physical Modeling and Stability Analysis

Factors that cause decreases in shear strengths in slope:

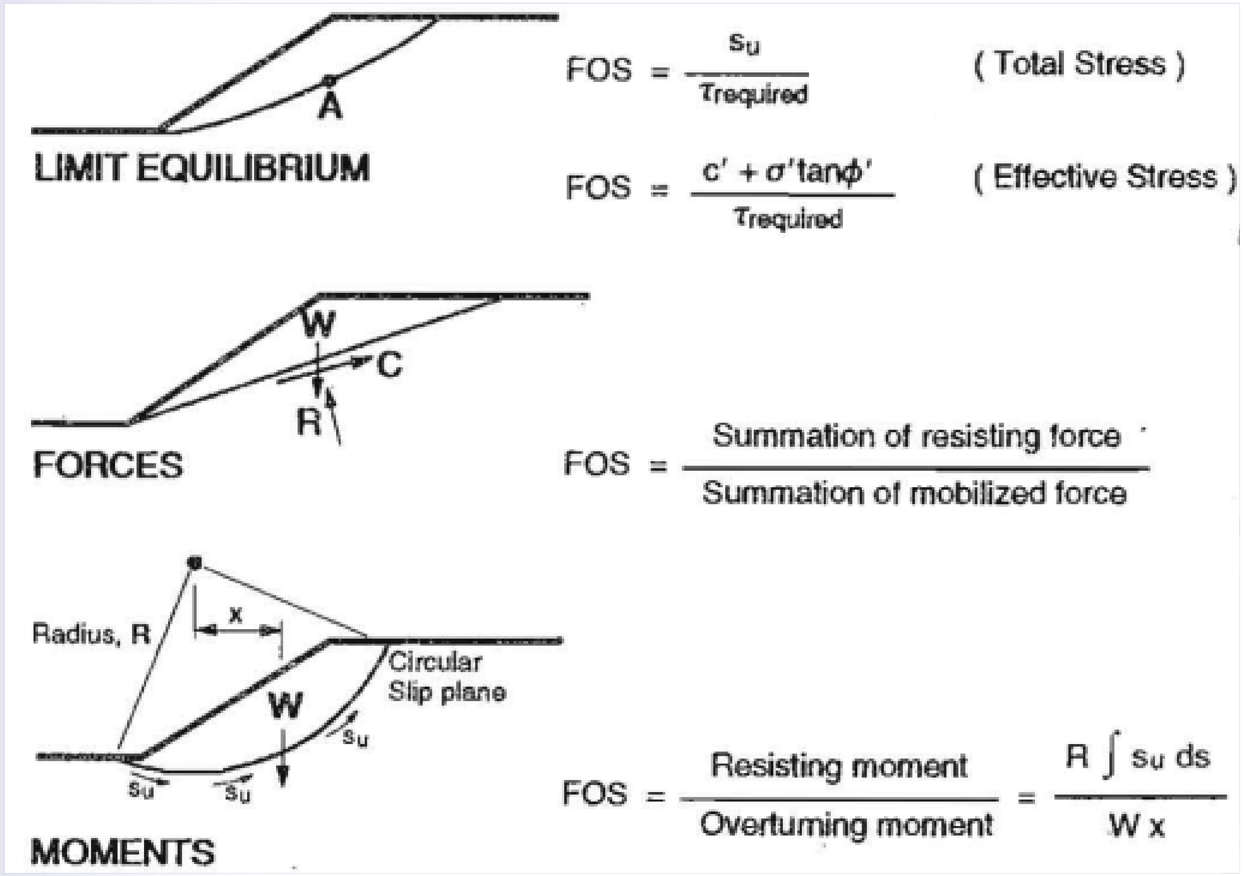
Factors inherent in the nature of the materials →
- A. Composition
- B. Structure
- C. Secondary or inherited structures
- D. Stratification

Changes caused by weathering and physiochemical activity →
- A. Wetting and drying processes
- B. Hydration
- C. Removal of cementing agents

Effect of pore pressures

Changes in structure →
- A. Stress release
- B. Structural degradation

4. Physical Modeling and Stability Analysis

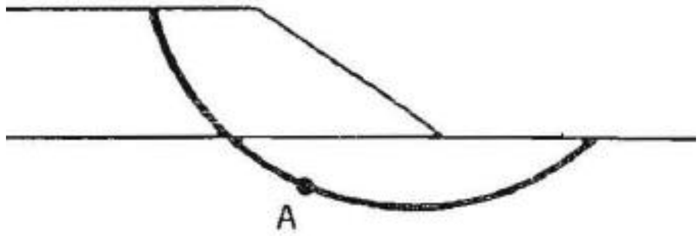


4. Physical Modeling and Stability Analysis

Embankments on Weak Foundations

Embankments are sometimes built on weak foundation materials. Sinking, spreading, and piping failures may occur irrespective of the stability of the new overlying embankment material. Consideration of the internal stability of an embankment-foundation system, rather than just the embankment, may be necessary. A simple rule of thumb based on **bearing capacity theory** can be used to make a preliminary estimate of the factor of safety against circular arc failure for an embankment built over a clay foundation. The rule is (Cheney and Chassie, 1982)

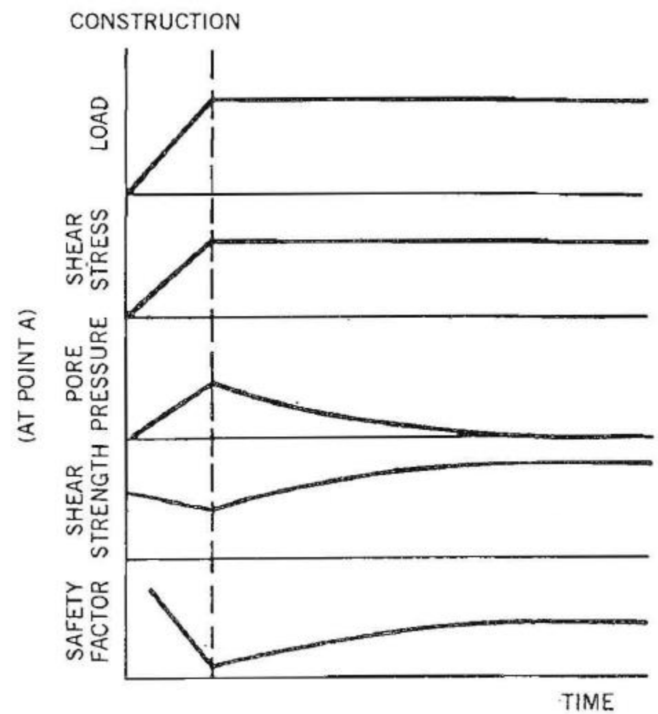
$$\mathrm{FOS} = \frac{6c}{\gamma_{\mathrm{fill}} \times H_{\mathrm{fill}}}$$



4. Physical Modeling and Stability Analysis

Embankments on Weak Foundations

$$\mathrm{FOS} = \frac{6c}{\gamma_{\mathrm{fill}} \times H_{\mathrm{fill}}}$$

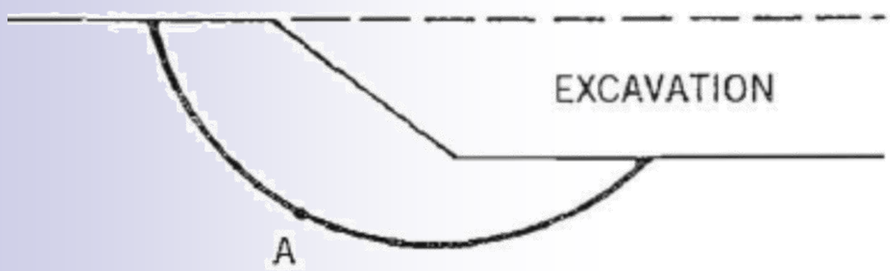


Stability conditions for an embankment slope over a clay foundation (from Bishop and Bjerrum, 1960, reproduced by permission of ASCE).

4. Physical Modeling and Stability Analysis

Shallow and deep cuts are important features in any civil engineering project. The aim in a slope design is to determine a height and inclination that is economical and that will remain stable for a reasonable life span. The design is influenced by the purposes of the **cut, geological condition, in situ material properties, seepage pressure, construction methods, and the potential occurrence of natural phenomena**, such as heavy precipitation, flooding, erosion, freezing, and earthquakes.

4. Physical Modeling and Stability Analysis



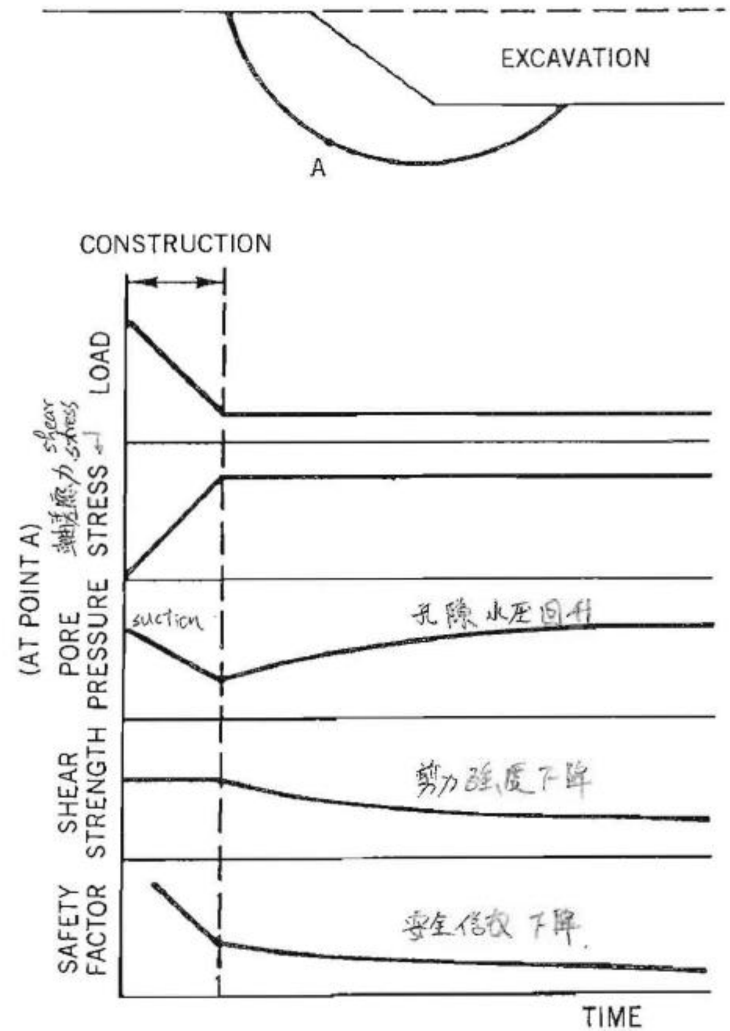
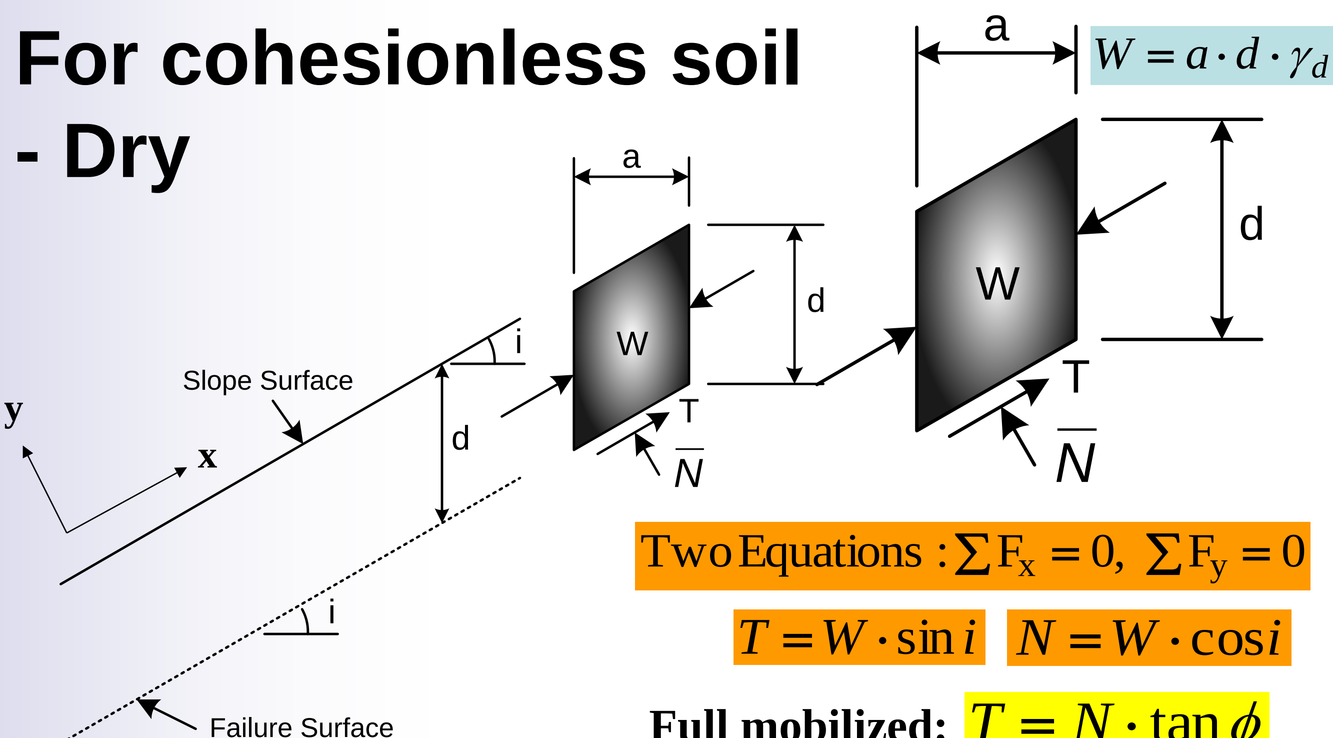


Figure 1.8 Stability conditions for a cut slope (from Bishop and Bjerrum, 1960, reproduced by permission of ASCE).

4. Physical Modeling and Stability Analysis- Infinite Slope

For cohesionless soil - Dry



$W = a \cdot d \cdot \gamma_d$

$\text{Two Equations}: \sum F_x = 0, \ \sum F_y = 0$

$T = W \cdot \sin i$ $\quad$ $N = W \cdot \cos i$

Full mobilized: $T = N \cdot \tan\phi$

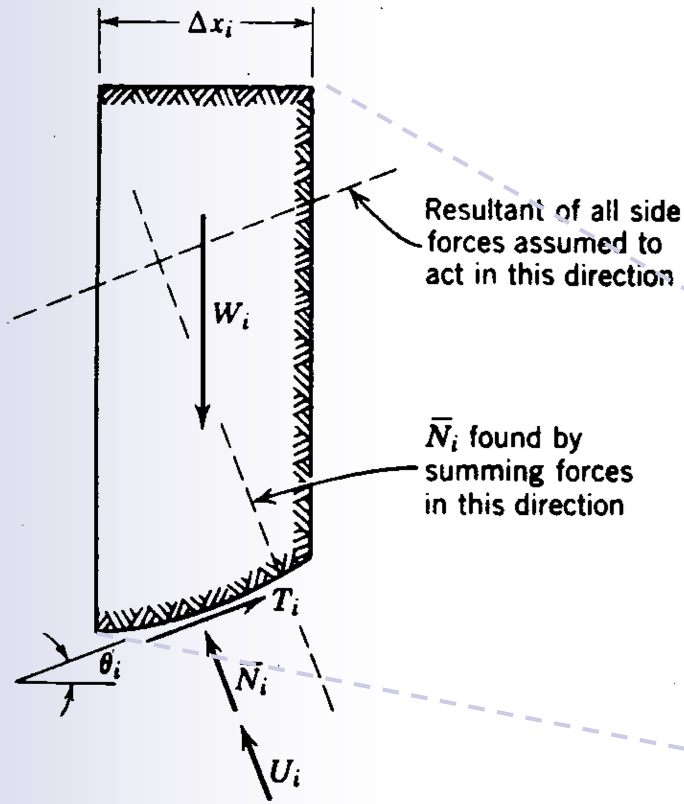
$\text{Two Unknowns}: \overline{N}, \ FS \Rightarrow i$

$\overline{N}, \ i \Rightarrow FS$

$$FS = \frac{W \cos i \tan\phi}{W \sin i} = \frac{\tan\phi}{\tan i}$$

***FS* < 1, ie. *i* > *ϕ* ; Slide occurred !!**

4. Physical Modeling and Stability Analysis- Slice Method



$$\overline{N}_i = W_i \cdot \cos\theta_i - U_i$$

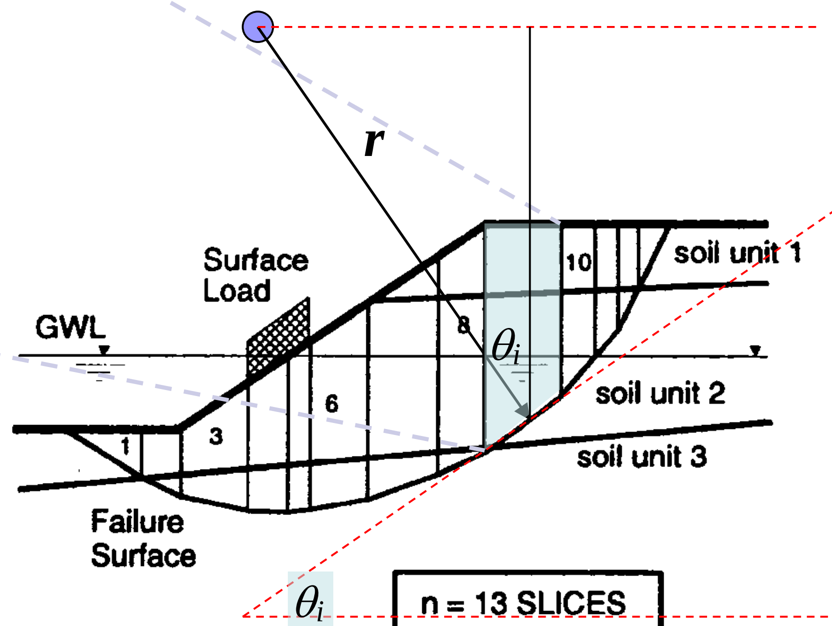


Figure 6.21 Division of potential sliding mass into slices.

4. Physical Modeling and Stability Analysis- Slice Method

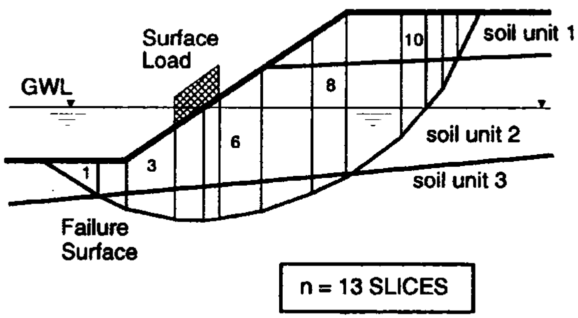
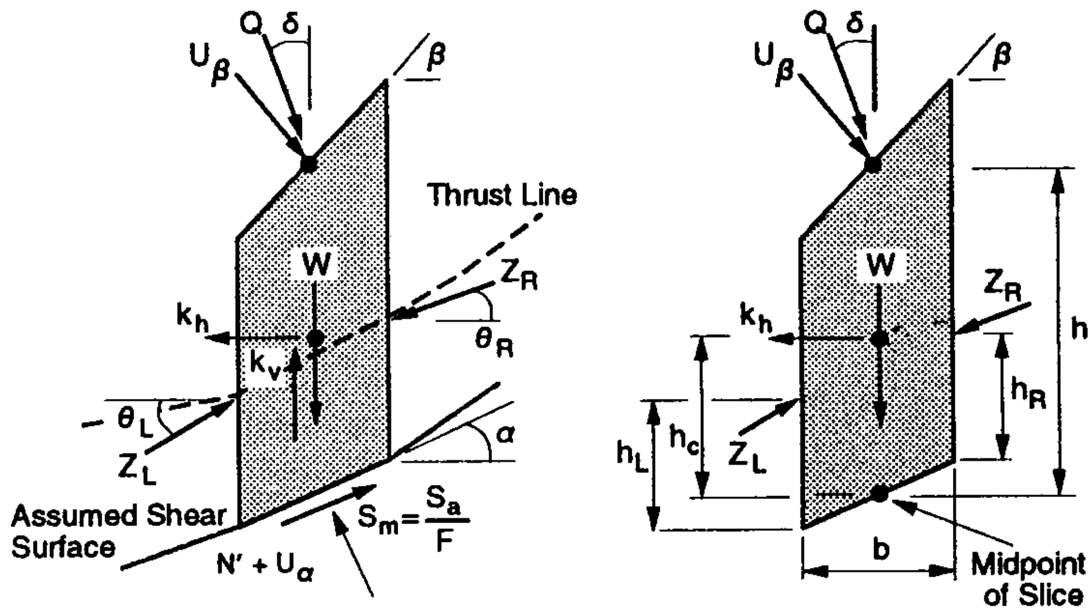


Figure 6.21 Division of potential sliding mass into slices.



F	=	factor of safety
S_a	=	available strength
	=	$C + N' \tan\phi$
S_m	=	mobilized strength
U_α	=	pore water force
U_β	=	surface water force
W	=	weight of slice
N′	=	effective normal force
Q	=	external surcharge
k_v	=	vertical seismic coefficient
k_h	=	horizontal seismic coefficient

Z_L	=	left interslice force
Z_R	=	right interslice force
θ_L	=	left interslice force angle
θ_R	=	right interslice force angle
h_L	=	height to force Z_L
h_R	=	height to force Z_R
α	=	inclination of slice base
β	=	inclination of slice top
b	=	width of slice
h	=	average height of slice
h_c	=	height to centroid of slice

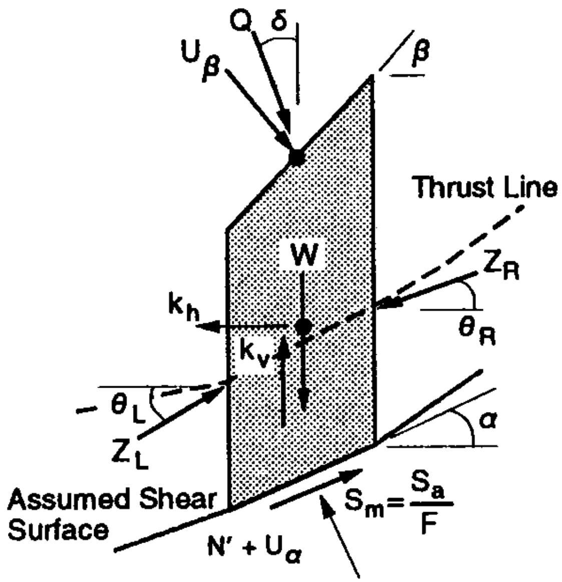


TABLE 6.4 Equations and Unknowns Associated with the Method of Slices

Equations	Condition
n	Moment equilibrium for each slice
$2n$	Force equilibrium in two directions (for each slice)
n	Mohr–Coulomb relationship between shear strength and normal effective stress
$4n$	Total number of equations

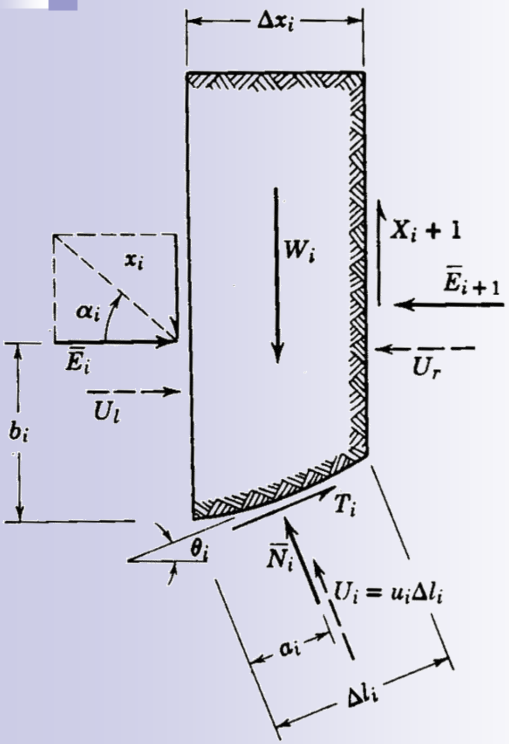
Unknowns	Variable
1	FOS
n	Normal force at base of each slice, N'
n	Location of normal force, N'
n	Shear force at base of each slice, S_m
$n-1$	Interslice force, Z
$n-1$	Inclination of interslice force, θ
$n-1$	Location of interslice force (line of thrust)
$6n-2$	Total number of unknowns

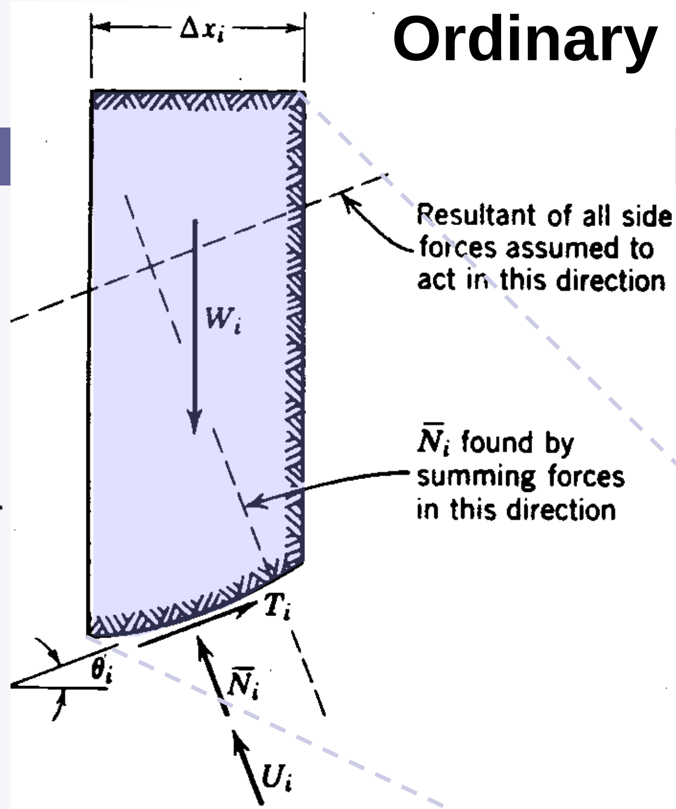
Table C-1
Unknowns and Equations for Limit Equilibrium Methods

Unknowns	Number of Unknowns for n Slices
Factor of safety (F)	1
Normal forces on bottom of slices (N)	N
Interslice normal forces, E	n – 1
Interslice shear forces, X	n – 1
Location of normal forces on base of slice	N
Location of interslice normal forces	n – 1
TOTAL NUMBER OF UNKNOWNS	5n – 2
Equations	**Number of Equations for n Slices**
Equilibrium of forces in the horizontal direction, $\Sigma F_x = 0$	n
Equilibrium of forces in the vertical direction, $\Sigma F_y = 0$	n
Equilibrium of moments	n
TOTAL NUMBER OF EQUILIBRIUM EQUATIONS	3n

Unknowns vs. Equations

Ordinary Method of Slices (OMS)





Assumptions: neglects all interslice forces and fails to satisfy force equilibrium for the slide mass as well as for individual slices.

$$\overline{N}_i = W_i \cdot \cos\theta_i - U_i$$

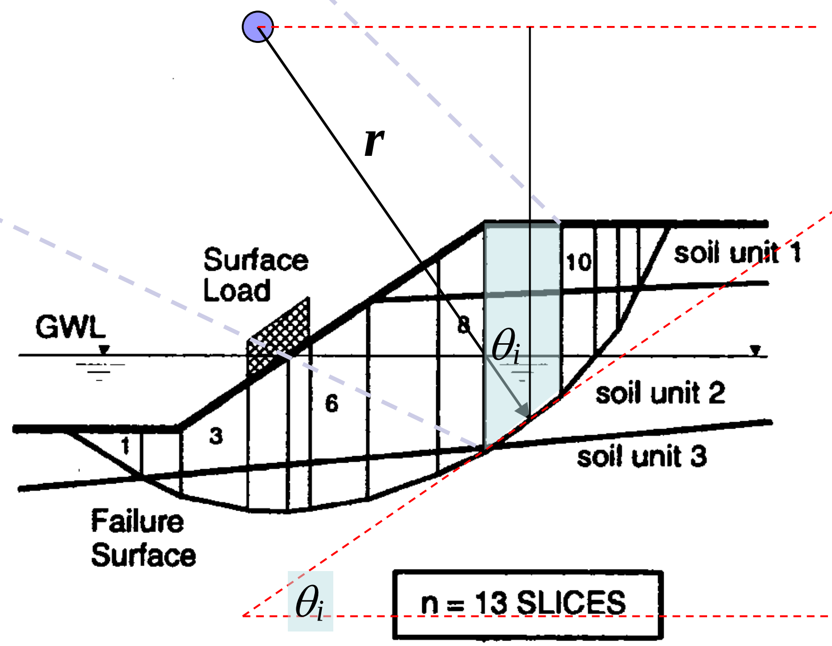
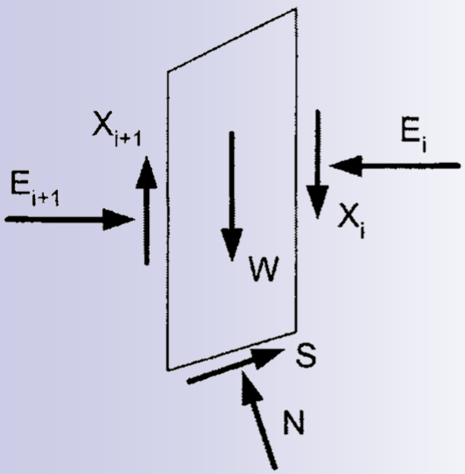


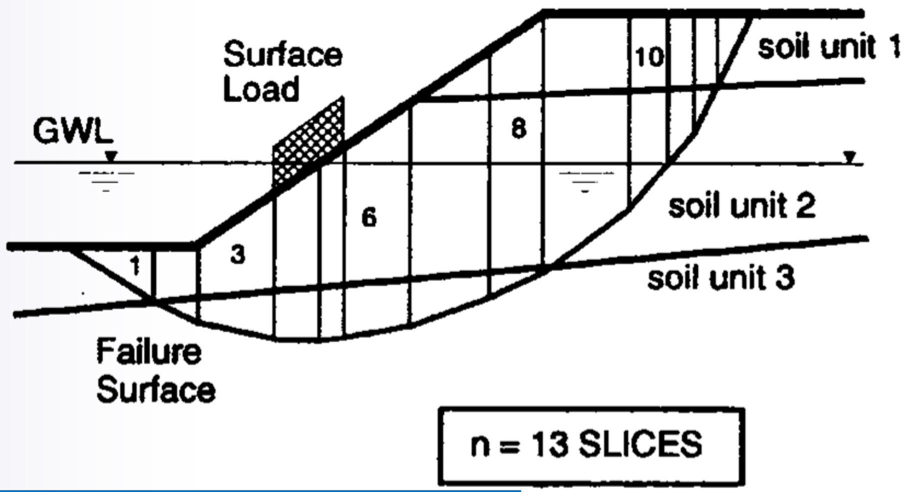
Figure 6.21 Division of potential sliding mass into slices.

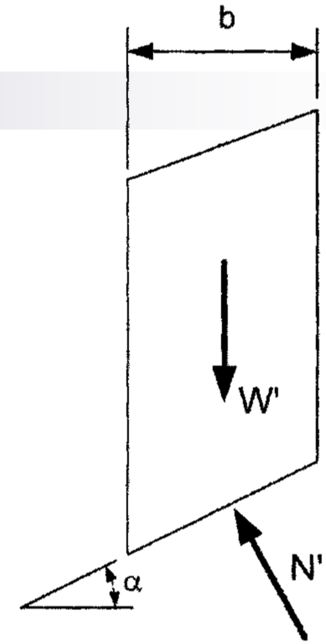
$$FS = \frac{M_r}{M_d} = \frac{\sum[(\bar{c}_i + \sigma_i \cdot \tan\bar{\phi}_i)\Delta l_i] \cdot r}{\sum W_i \cdot r \cdot \sin\theta_i \cdot}$$

$$= \frac{\sum(\bar{c}_i \cdot \Delta l_i + \overline{N}_i \cdot \tan\bar{\phi}_i) \cdot r}{\sum W_i \cdot r \cdot \sin\theta_i \cdot}$$

Ordinary Method of Slices (OMS)







$$N' = W' \cos(\alpha)$$

$$W' = W - ub$$

$$N' = (W - ub)\cos(\alpha)$$

TABLE 6.5 Static Equilibrium Conditions Satisfied by Limit Equilibrium Methods

Method	Force–Equilibrium x	Force–Equilibrium y	Moment Equilibrium	each slice, overall
Ordinary method of slices (OMS)	No	No	Yes	$\Sigma F_\alpha = 0, \Sigma M_o = 0$
Bishop's simplified	Yes	No	Yes	$\Sigma F_v = 0$, $F_H = 0$
Janbu's simplified	Yes	Yes	No	$\Sigma F_v = 0$, $\Sigma M_o = 0$

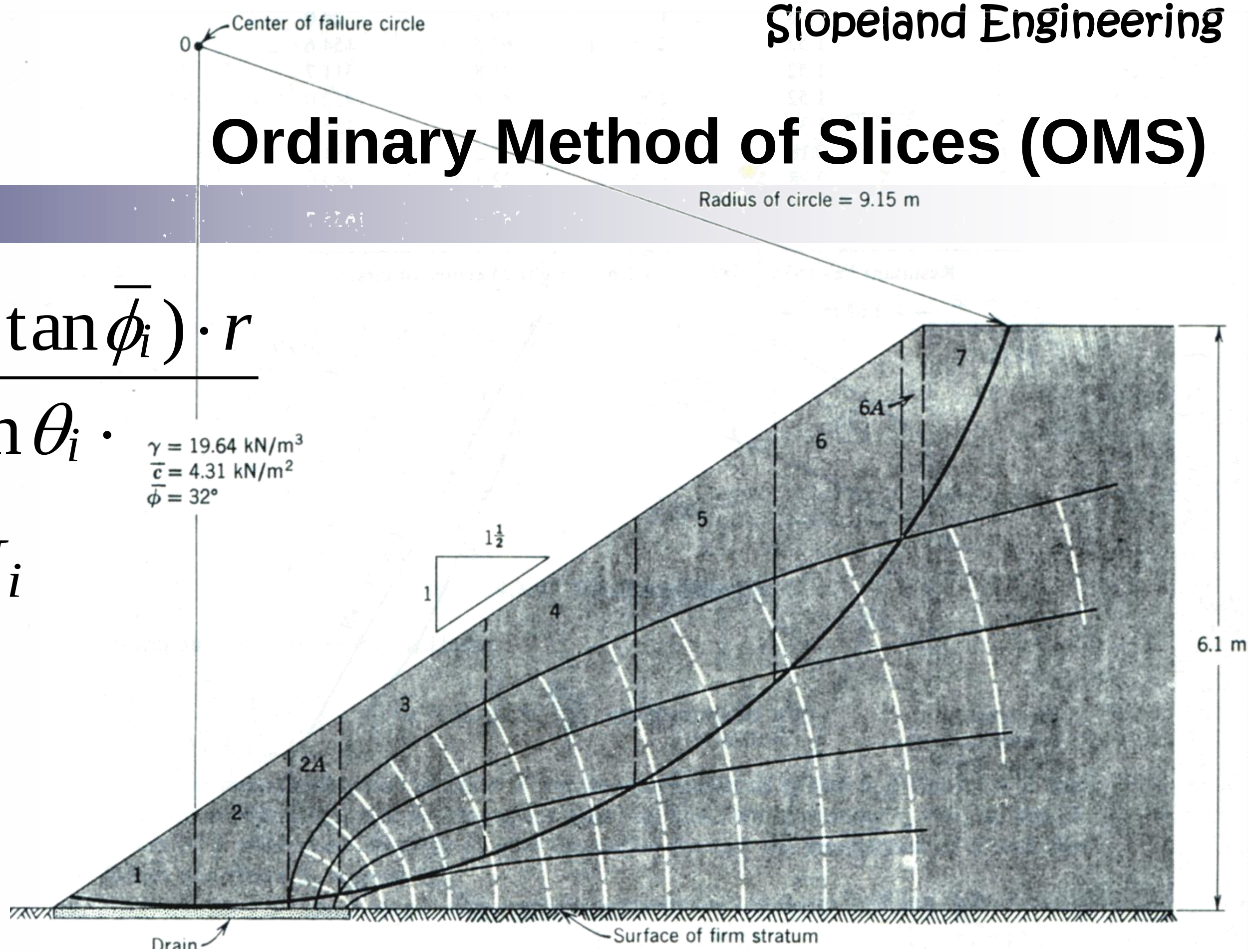
Table C-3
Unknowns and Equations for the Ordinary Method of Slices Procedure

Unknowns	**Number of Unknowns for n Slices**
Factor of safety (F)	1
TOTAL NUMBER OF UNKNOWNS	1
Equations	**Number of Equations for n Slices**
Equilibrium of moments of the entire soil mass	1
TOTAL NUMBER OF EQUILIBRIUM EQUATIONS	1

Ordinary Method of Slices (OMS)

$$FS = \frac{\sum(\bar{c}_i \cdot \Delta l_i + \bar{N}_i \cdot \tan\bar{\phi}_i) \cdot r}{\sum W_i \cdot r \cdot \sin\theta_i \cdot}$$

$$\bar{N}_i = W_i \cdot \cos\theta_i - U_i$$



Slice	W_i (kN)	$\sin\theta_i$	$W_i \sin\theta_i$ (kN)	$\cos\theta_i$	$W_i \cos\theta_i$ (kN)	u_i (kN/m)	Δl_i (m)	U_i (kN)	$\bar{N}_i$ (kN)
1	13.2	−0.03	−0.4	1.00	13.2	0	1.34	0	13.2
2	24.6	0.05	1.2	1.00	24.6	0	0.98	0	24.6
2A	19.1	0.14	2.7	0.99	18.9	1.4	0.58	0.8	18.1
3	67.5	0.25	19.6	0.97	65.5	10.0	1.62	16.2	49.3
4	81.8	0.42	34.4	0.91	74.4	13.9	1.71	23.8	50.6
5	84.8	0.58	49.2	0.81	68.7	12.0	1.89	22.7	46.0
6	67.4	0.74	49.9	0.67	45.2	5.3	2.04	10.8	34.4
6A	7.2	0.82	5.9	0.57	4.1	0	0.37		4.1
7	22.3	0.87	19.4	0.49	10.9	0	2.23	0	10.9
			181.9				12.76		251.2

4. Physical Modeling and Stability Analysis- Slice Method

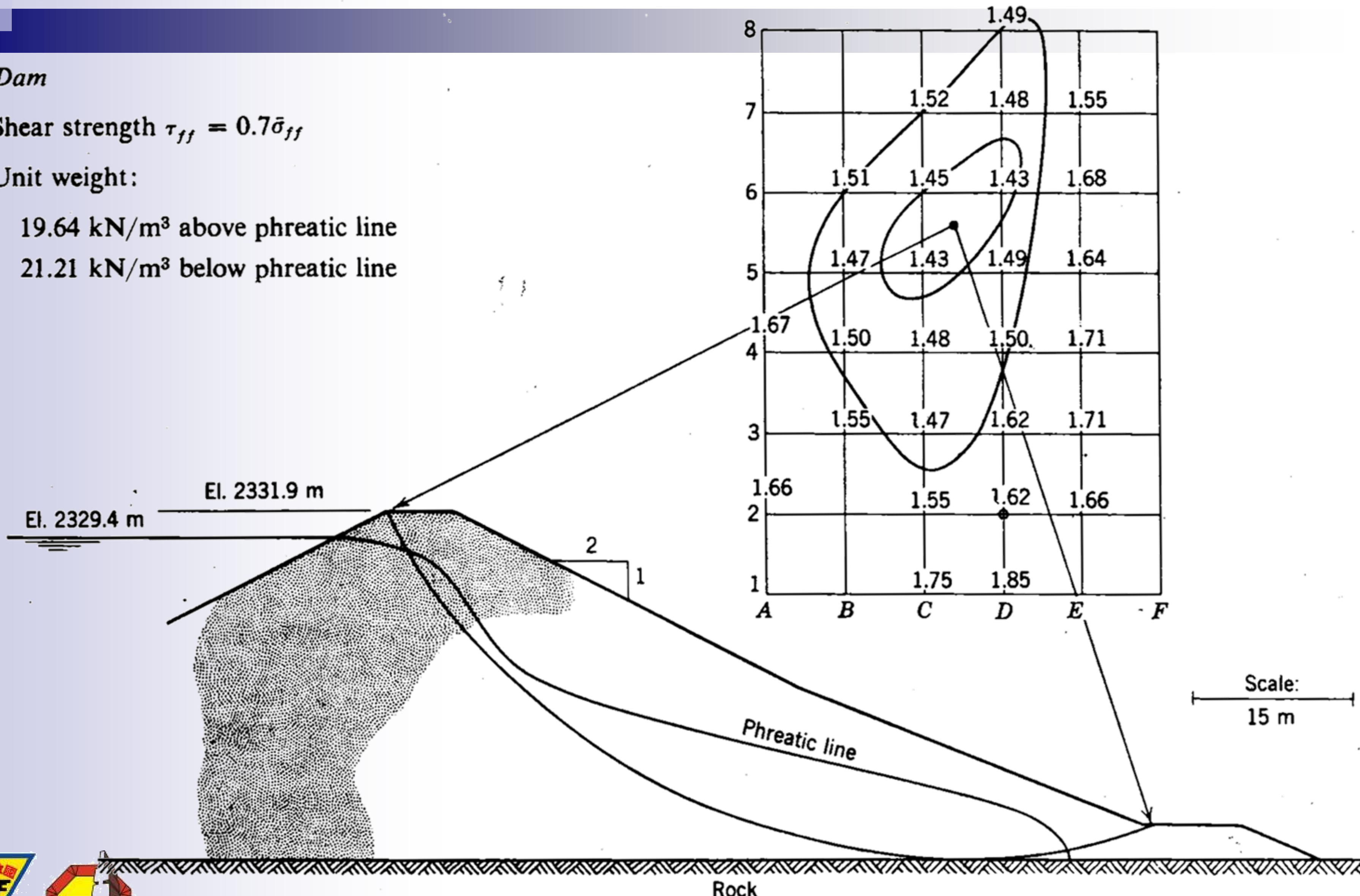
Dam

Shear strength $\tau_{ff} = 0.7\bar{\sigma}_{ff}$

Unit weight:

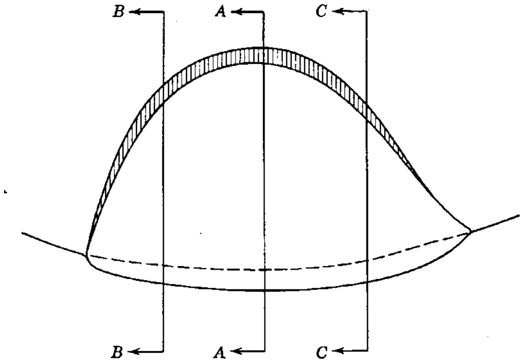
19.64 kN/m³ above phreatic line

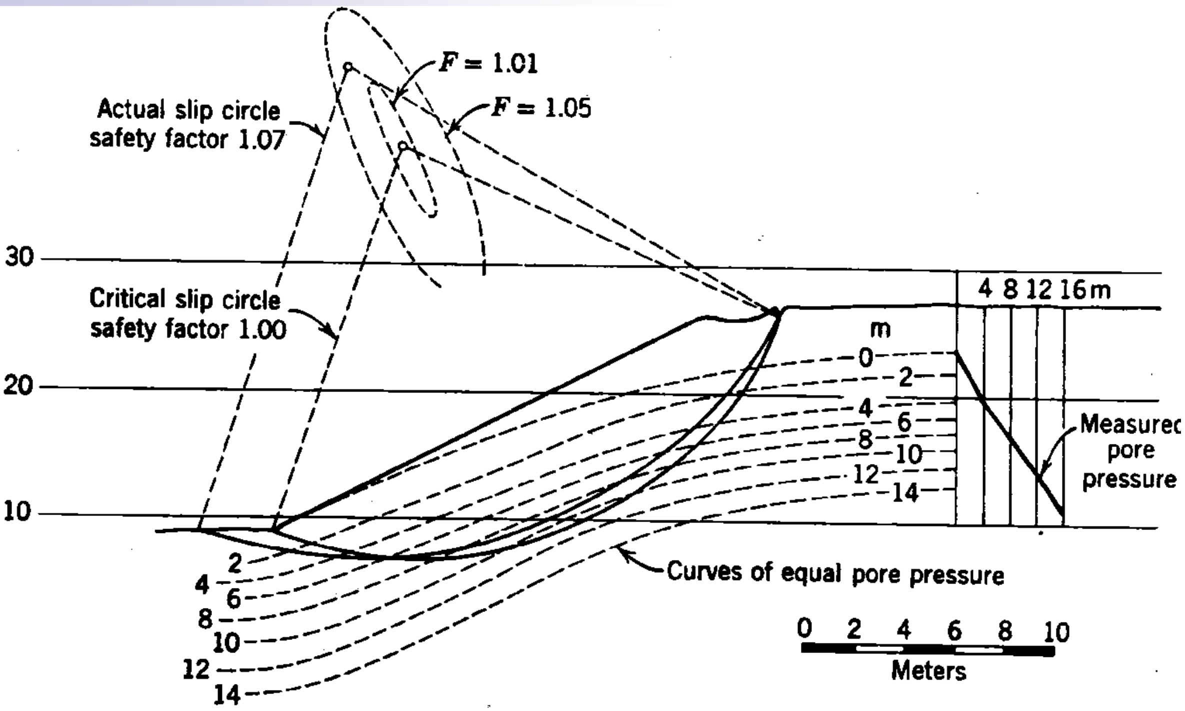
21.21 kN/m³ below phreatic line

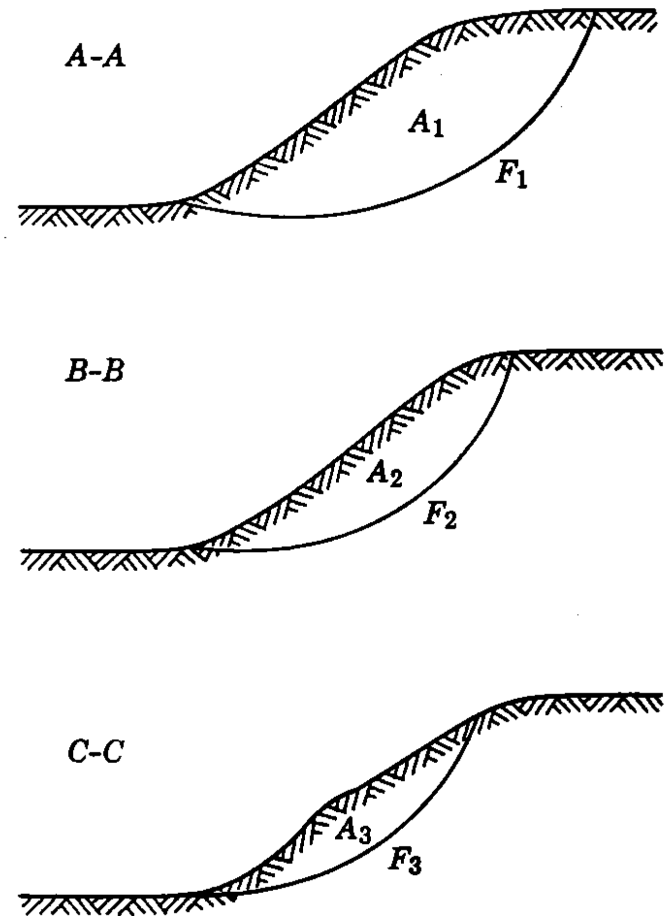


4. Physical Modeling and Stability Analysis- Slice Method

$$F = \frac{F_1 A_1 + F_2 A_2 + F_3 A_3}{A_1 + A_2 + A_3}$$







Section No.	Safety factor $\bar{c}\ \bar{\phi}$,-analysis
1	1.10
2	1.00
3	1.19

Weighted average safety factor for the whole slide $F = 1.05$

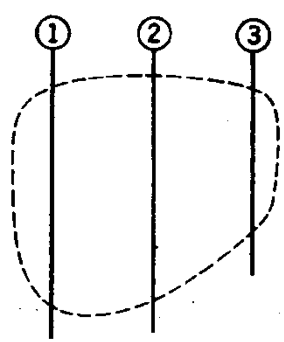
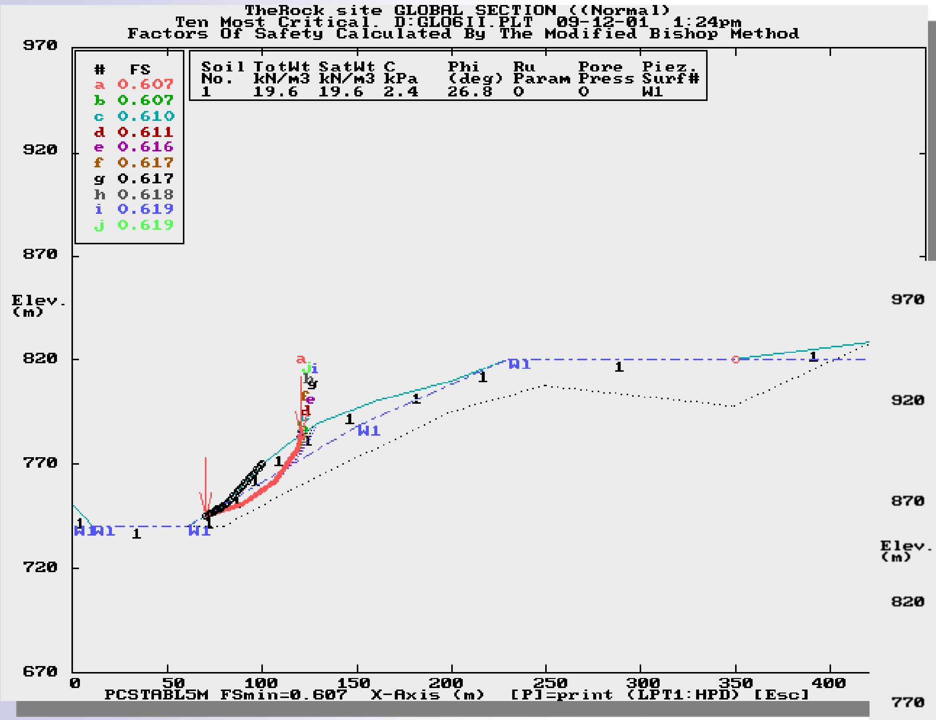
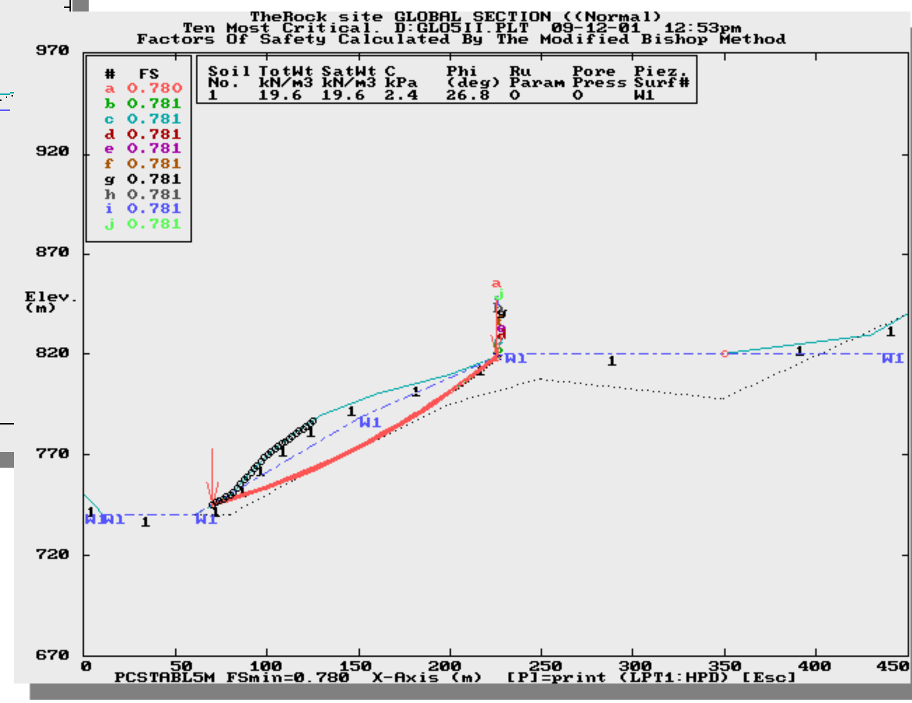


Fig. 24.18 Analysis of slide at Lodalen, Norway (From Bishop and Bjerrum, 1960).

4. Physical Modeling and Stability Analysis- Slice Method





4. Physical Modeling and Stability Analysis

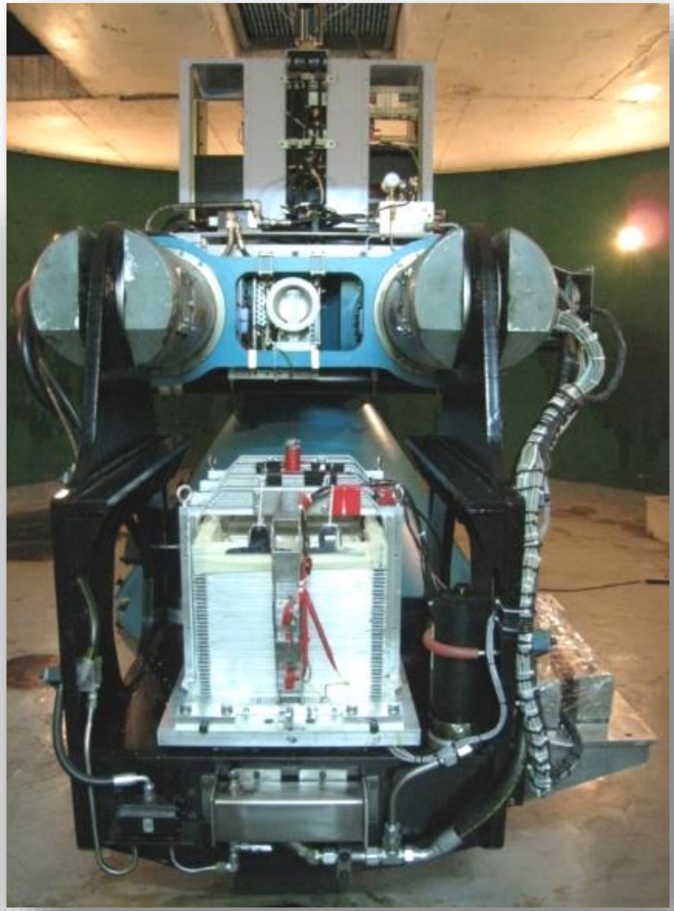
- Natural slopes that have been stable for many years may suddenly fail because of changes in topography, seismicity, groundwater flows, loss of strength, stress changes, and weathering.
- Generally, these failures are not understood well because little study is made until the failure makes it necessary. In many instances, significant uncertainty exists about the stability of a natural slope.

4. Physical Modeling and Stability Analysis

- Peck (1967) emphasized that:

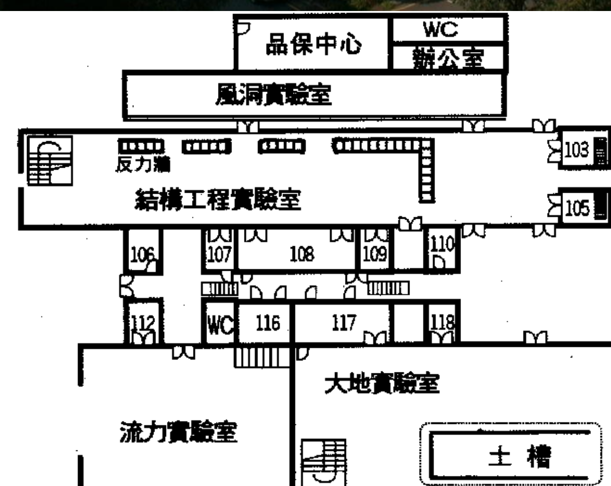
Our chances for prediction of the stability of a natural slope are perhaps best if the area under study is an old-slide zone which has been studied previously and may be reactivated by some human operations such as excavating into the toe of the slope. On the other hand, our chances are perhaps worst if the mechanism triggering the landslide is (1) at a random not previously studied location and (2) a matter of probability such as the occurrence of an earthquake.

4. Physical Modeling and Stability Analysis



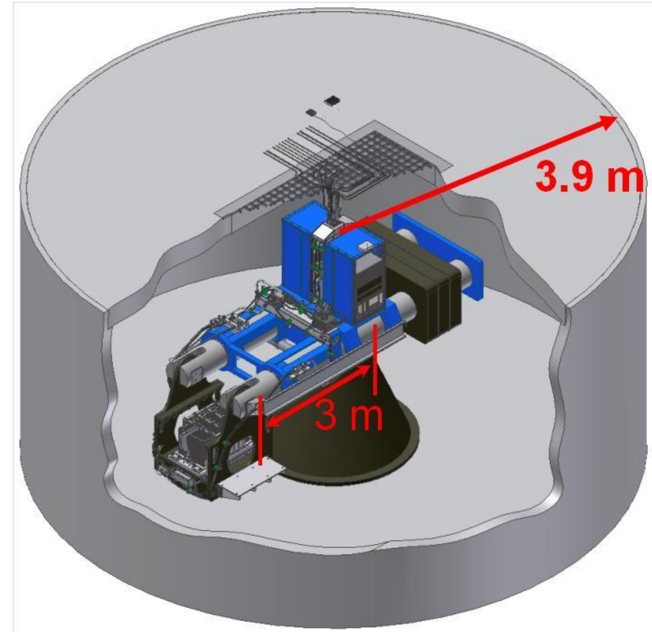
4. Physical Modeling and Stability Analysis

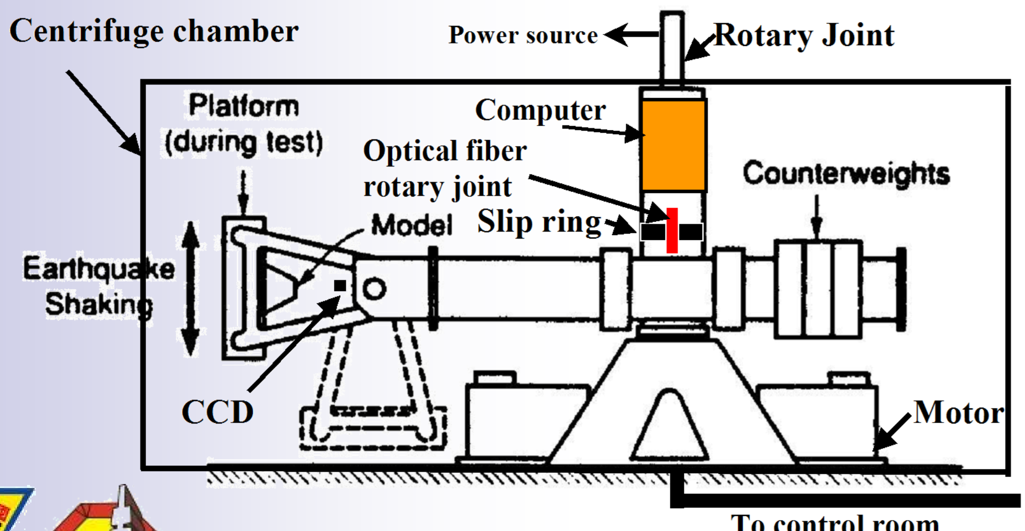
NCU-Experimental Center for Civil Engineering



4. Physical Modeling and Stability Analysis

NCU Geotechnical Centrifuge

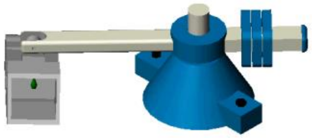




Nominal radius	3 m
Max. Payload (Static Test)	1000kg
Capacity	100 g-ton

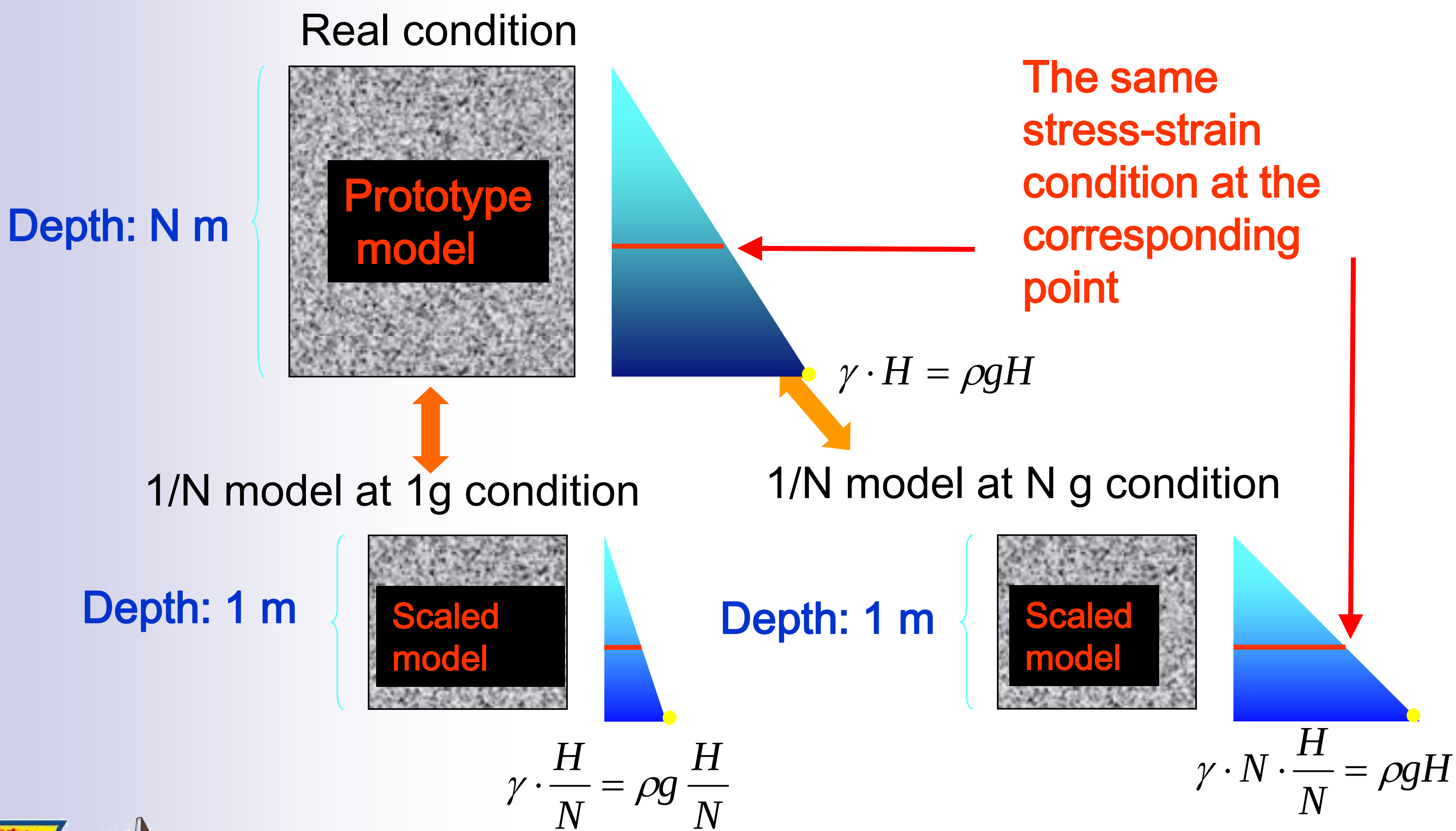
4. Physical Modeling and Stability Analysis

NCU Geotechnical Centrifuge



4. Physical Modeling and Stability Analysis

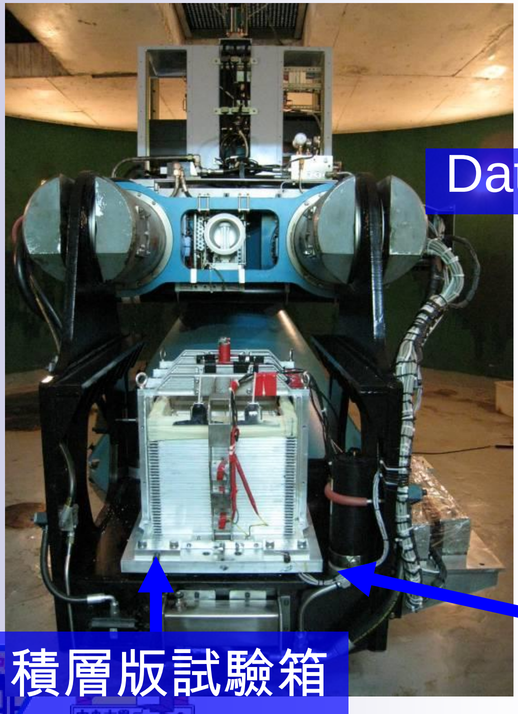
Physical modeling

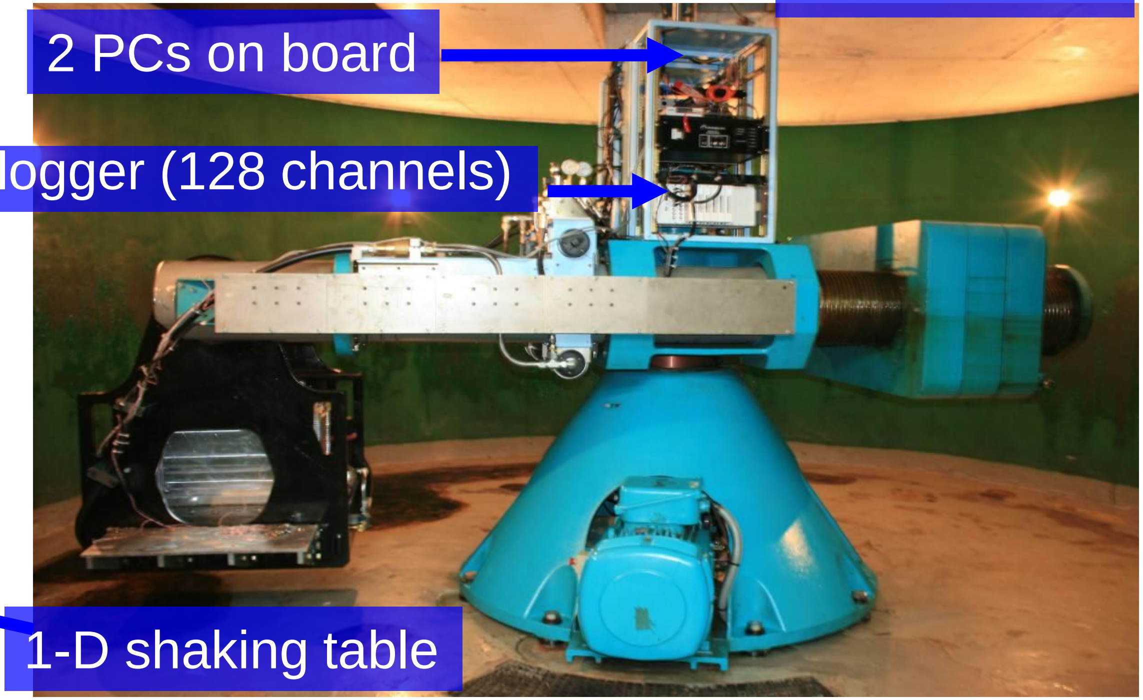


4. Physical Modeling and Stability Analysis

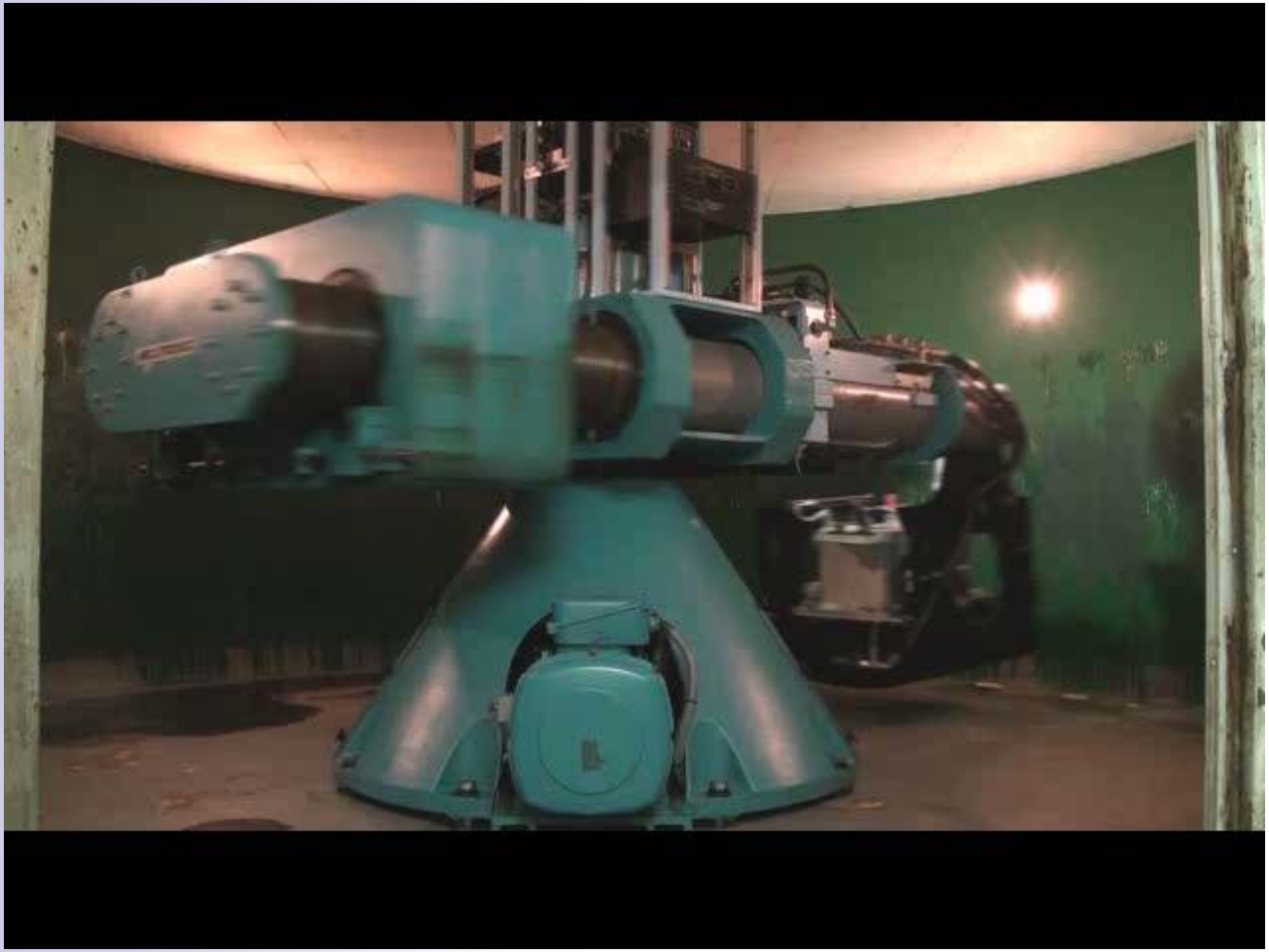
NCU-Centrifuge Shaking Table

Shaking direction	One direction
Nominal shaking force	± 53.4 kN
Max. shaking velocity	± 1 m/s
Max. table displacement	± 6.4 mm
Max. payload dimensions	1m×0.5m×0.5m (L×W×H)
Max. payload weight	400 kg
Nominal shaking frequency range	0-250 Hz
Max. centrifuge acceleration	80 g





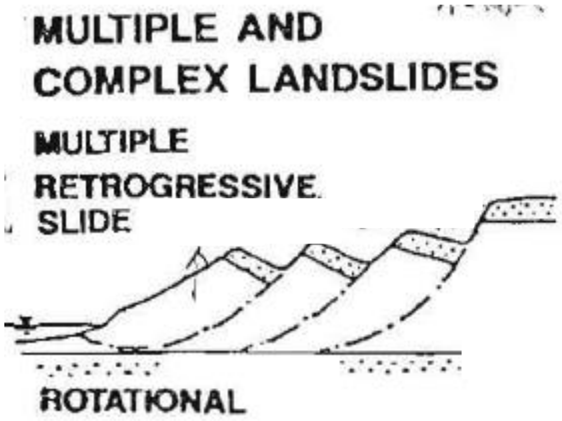
4. Physical Modeling and Stability Analysis

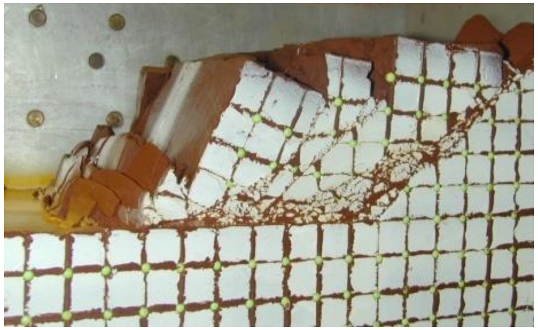


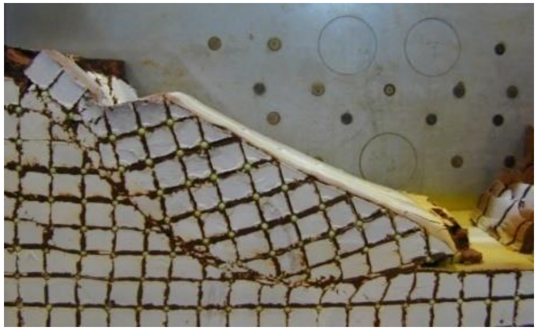
Research Topics of NCU Centrifuge Lab

- Soil Liquefaction
- Slope Stability
- Response of High-Level Waste Disposal

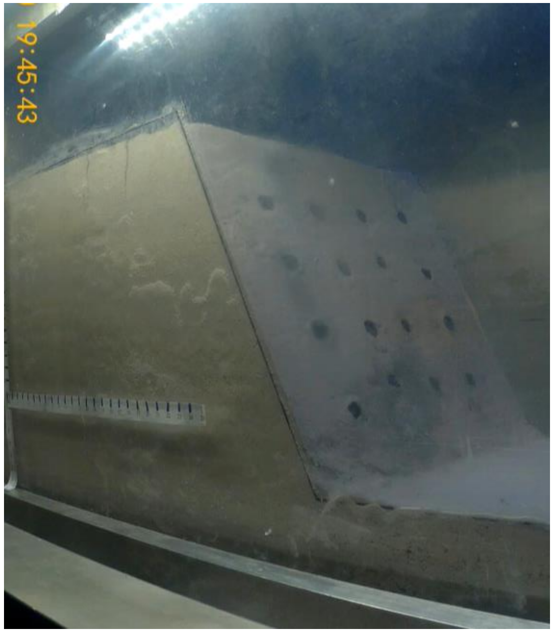
4. Physical Modeling and Stability Analysis





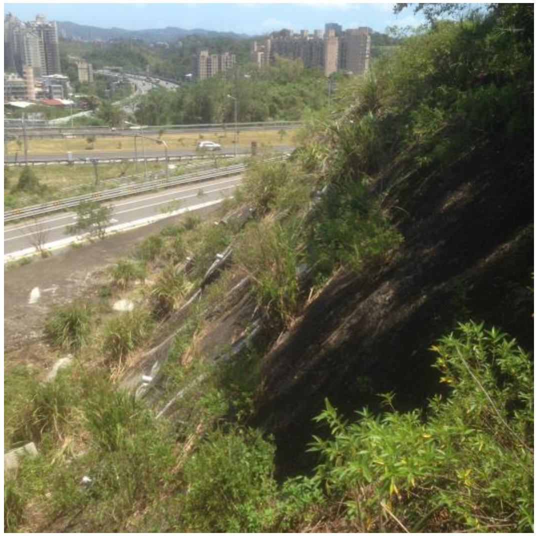


4. Physical Modeling and Stability Analysis

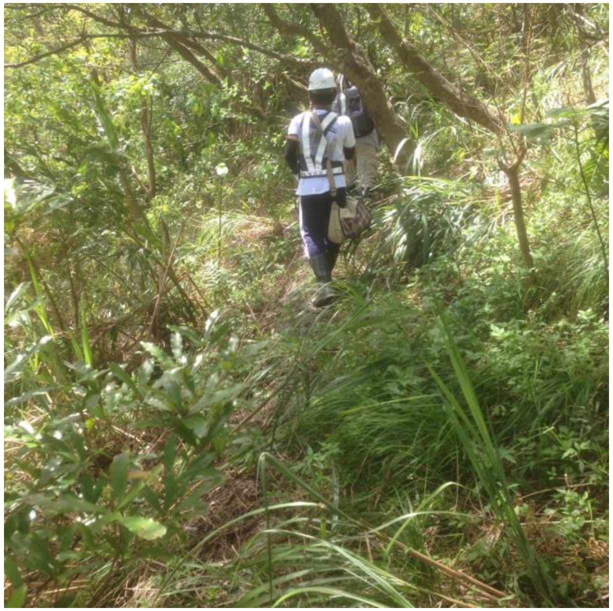


5. Countermeasures

5. Countermeasures



5. Countermeasures

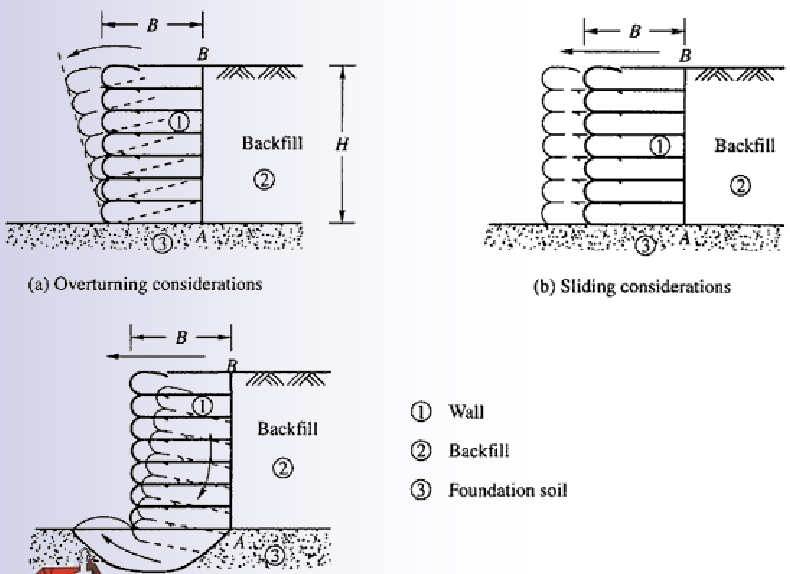

5. Countermeasures

Retaining structures are used in seven principal ways, as shown in Figures in below. The design of retaining structures requires three primary considerations:

(1) External stability of the soil behind and below the structure

(2) Internal stability of the retained backfill

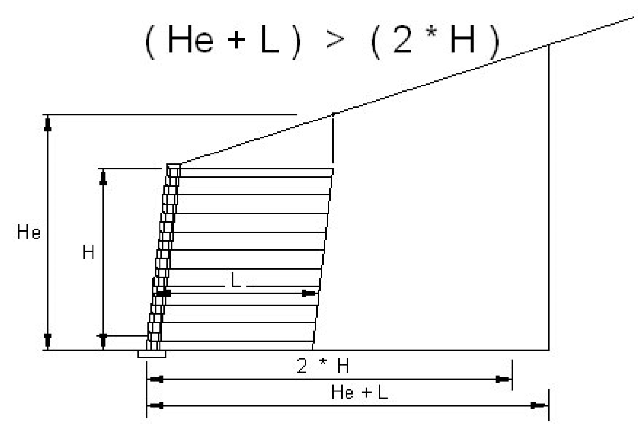
(3) Structural strength of retaining wall members



(a) Overturning considerations

(b) Sliding considerations

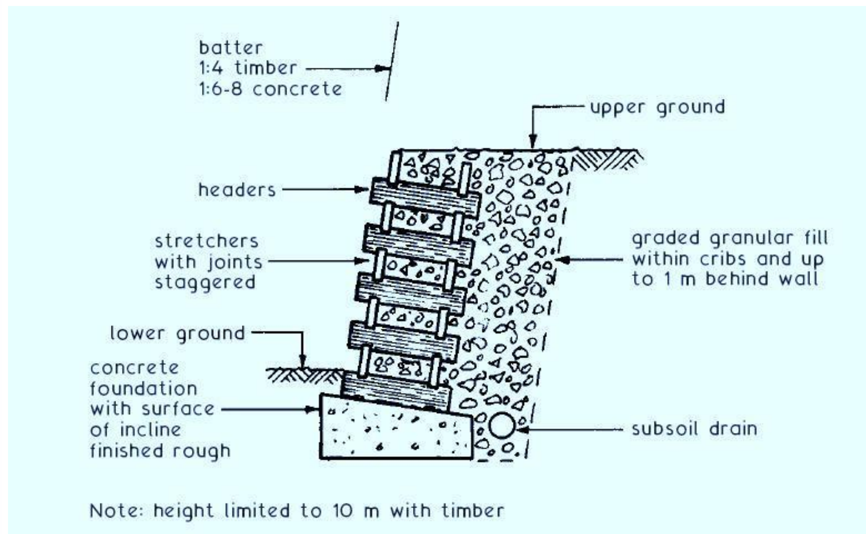
(c) Foundation considerations



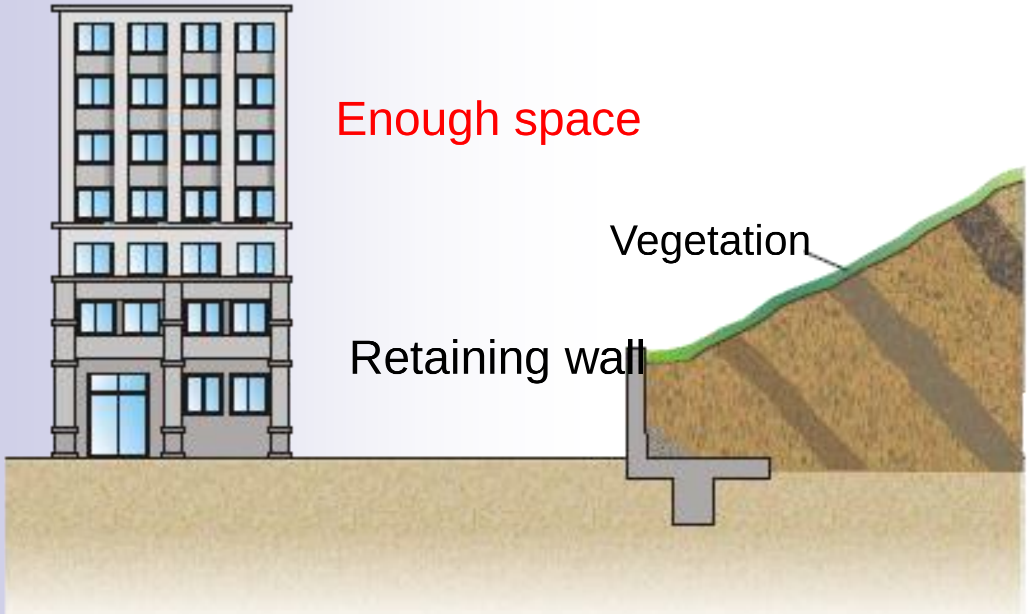
5. Countermeasures

Retaining structures are frequently used to support stable or unstable earth masses. The different types of retaining structures such as

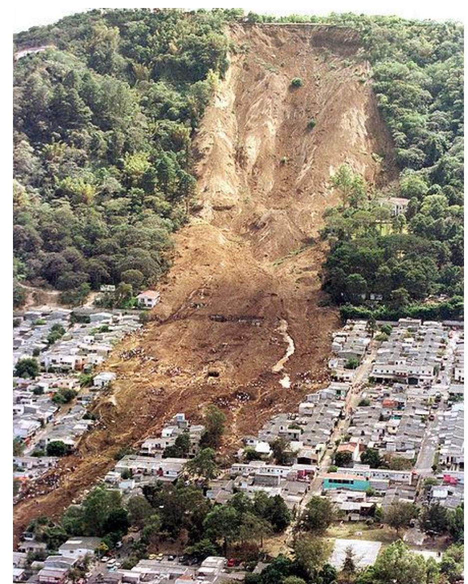
(1) Gravity walls (e.g. , masonry, concrete, cantilever, or crib walls)



5. Countermeasures



Drainage System

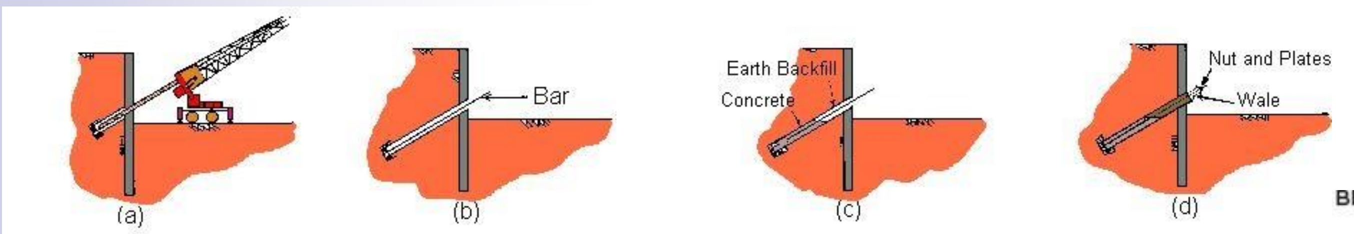


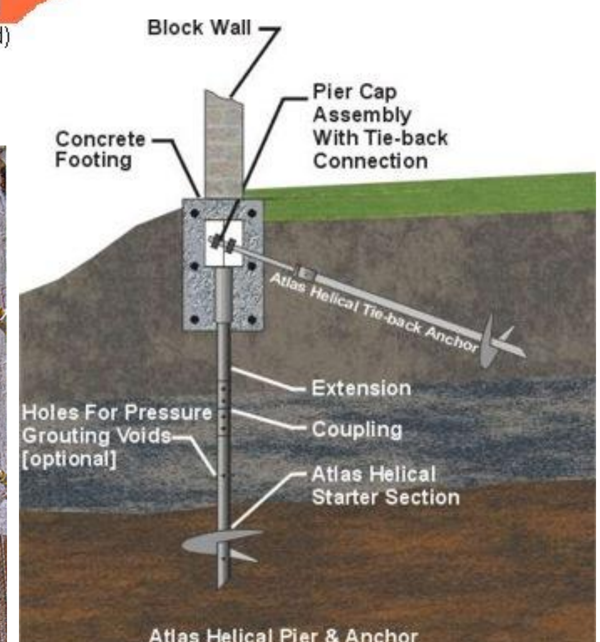
5. Countermeasures

Retaining structures are frequently used to support stable or unstable earth masses. The different types of retaining structures such as

(1) Gravity walls (e.g. , masonry, concrete, cantilever, or crib walls)

(2) Tieback or soil-nailed walls

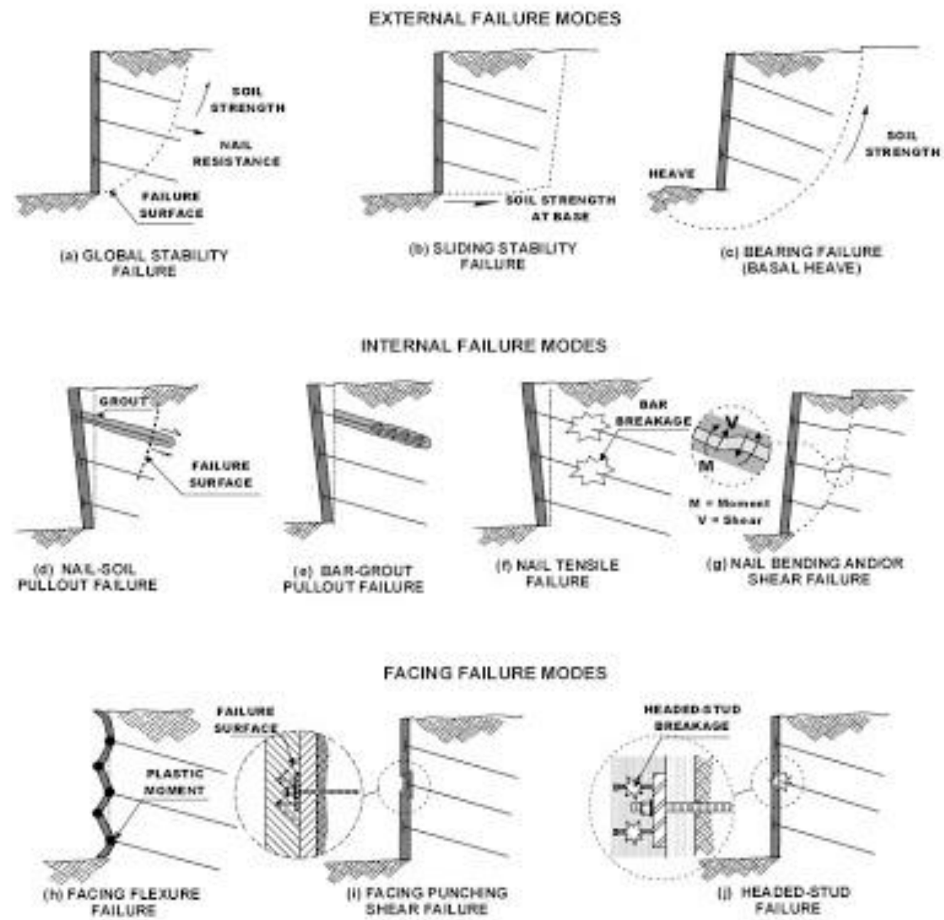




5. Countermeasures

Retaining structures are frequently used to support stable or unstable earth masses. The different types of retaining structures such as

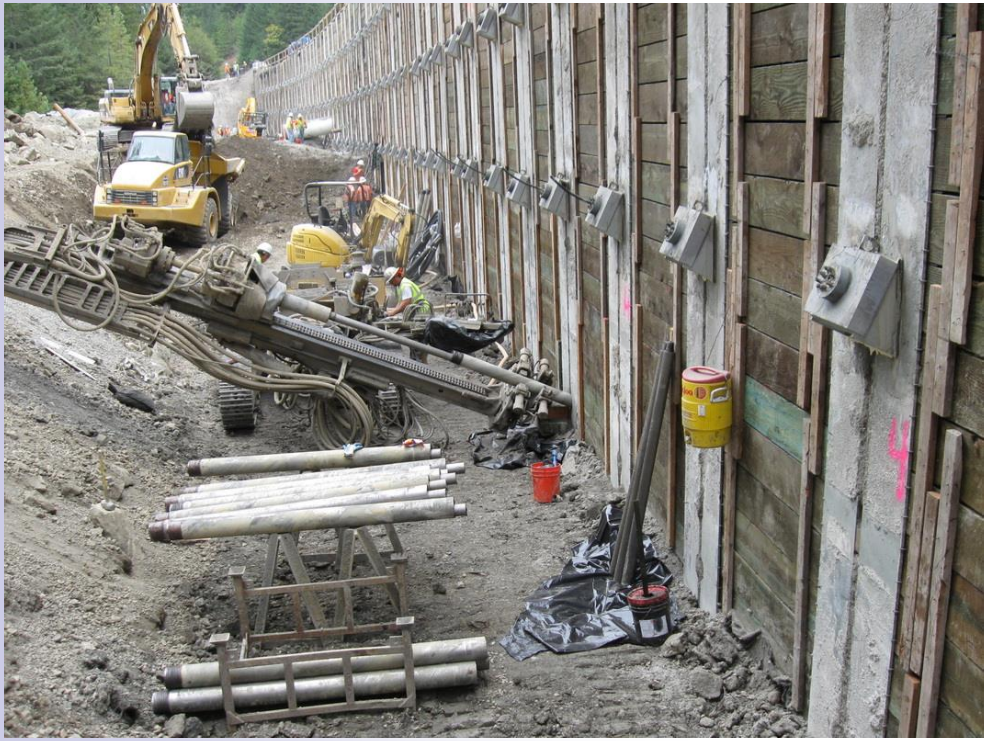
(2) Tieback or soil-nailed walls



5. Countermeasures

Retaining structures are frequently used to support stable or unstable earth masses. The different types of retaining structures such as

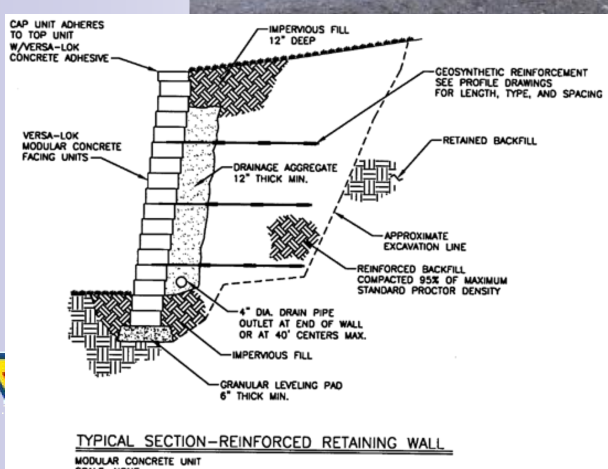
(3) Soldier pile and wooden lagging or sheet pile walls

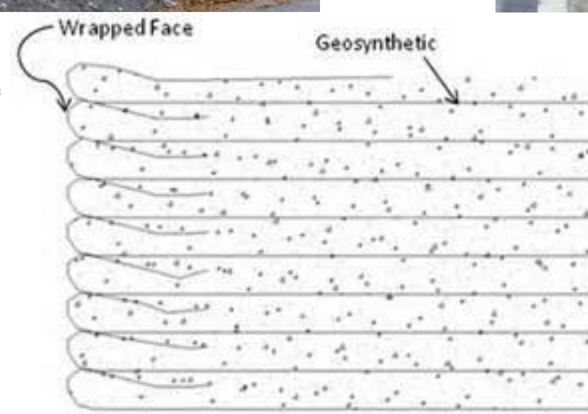


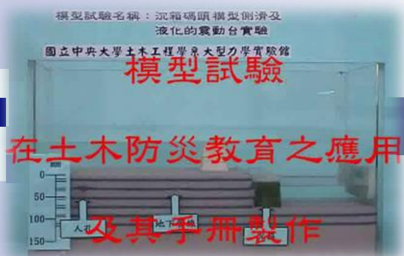
5. Countermeasures

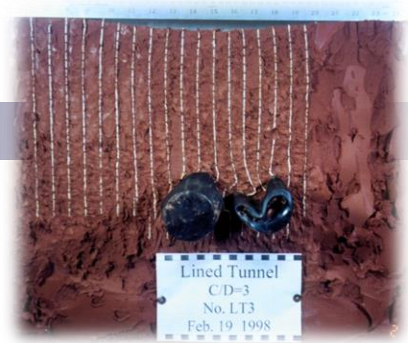
Retaining structures are frequently used to support stable or unstable earth masses. The different types of retaining structures such as

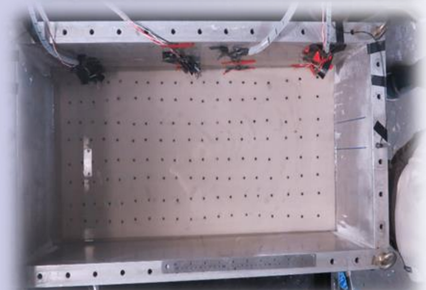
(4) Mechanically stabilized embankments including geosynthetic and geogrid reinforced walls











Thanks for your kind Attention!

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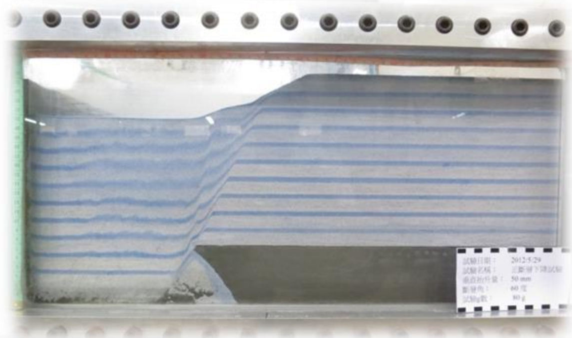
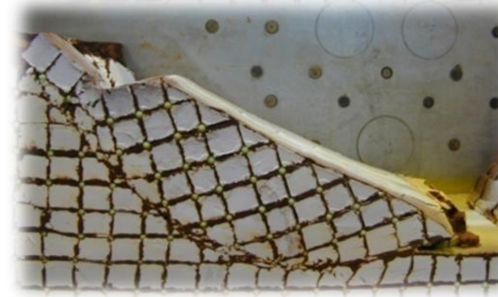
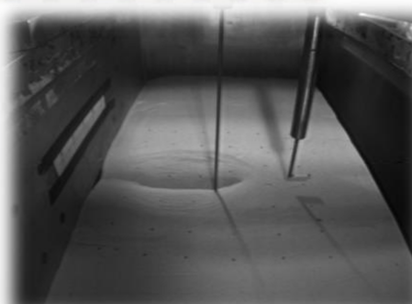
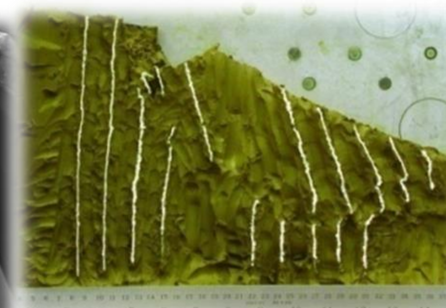
National Central University, Department of Civil Engineering









Homework

Please try to discuss about:

Is it possible to prevent the large scale slope failure?

What can we do for this kind of landslide? (Prevention, Mitigation and Recovery)