水土保持局技術研究發展小組專題討論

各類型岩坡破壞特性與穩定分析之研究



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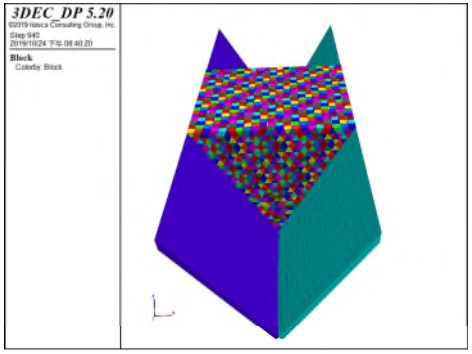

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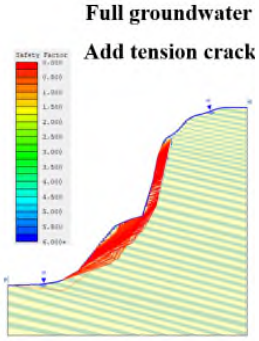

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羅佳明 林銘郎 黃文昭 翁孟嘉 李宏輝 王泰典

台大、 中大、交大、國防大學、聯大等土木工程學系團隊

2019/12/31

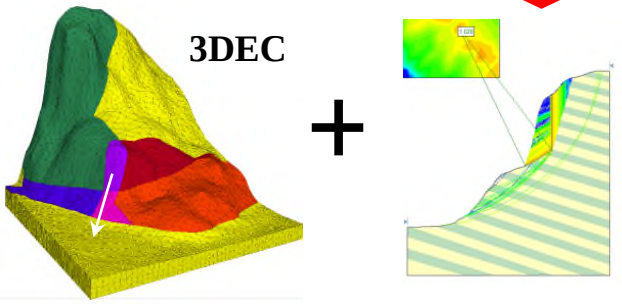
簡報大綱

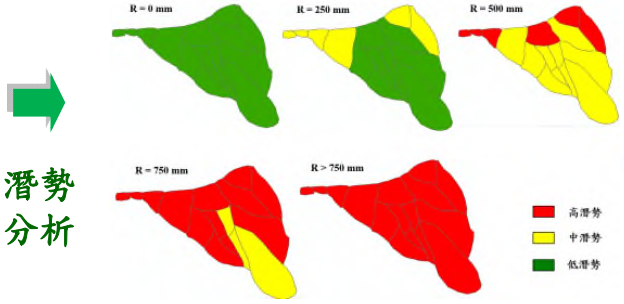


模型試驗與特性分析



數值分析

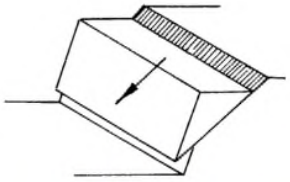




潛勢分析

1. 研究背景與研究方法簡介
2. 模型試驗設計與初步成果
3. 岩坡單元劃設與穩定分析
4. 整合團隊成果與未來精進項目

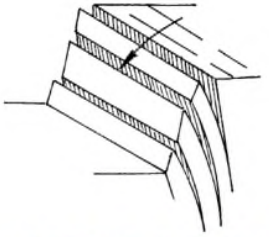
Stead & Wolter (2015)



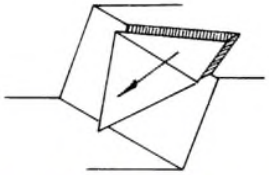
平面破壞模式 (Plane Failure Model)







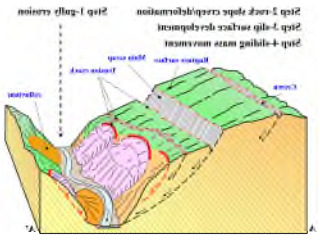
傾倒破壞模式 (Toppling Failure Model)



楔形破壞模式 (Wedge Failure Model)







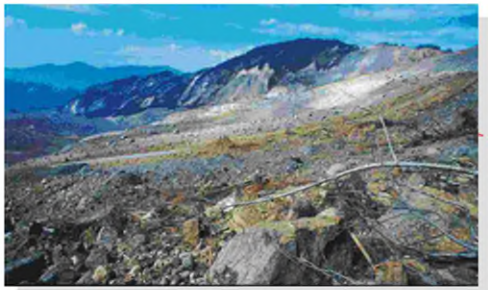
1 研究背景簡介



桃園合流部落岩坡崩滑 (李璟芳拍攝，2016)



國道3號3.1k順向坡崩滑 (空警隊拍攝，2010)



草嶺順向坡崩滑 (洪如江拍攝，1999)



烏來忠治里複合型山崩 (NCDR拍攝， 2016)

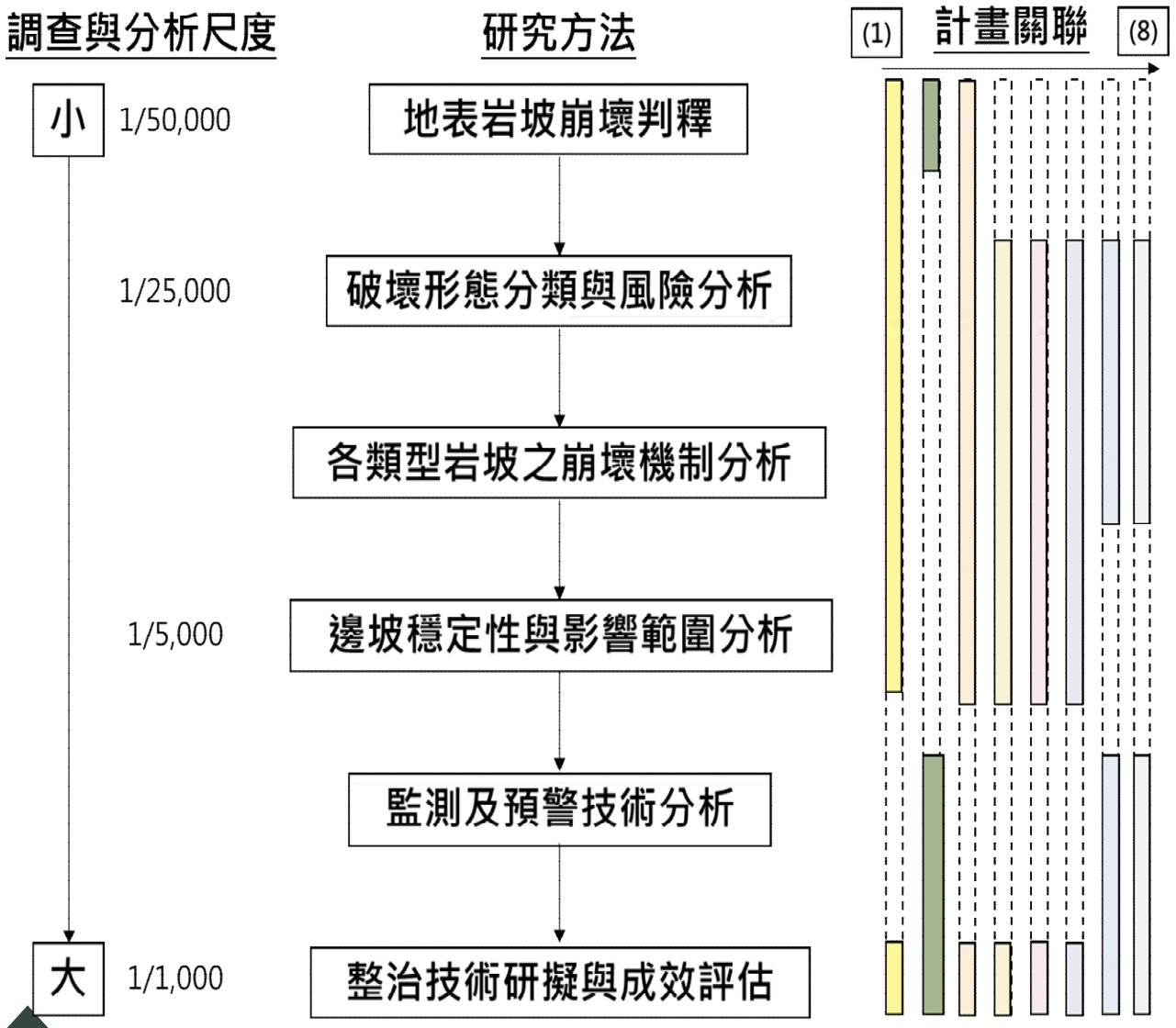


獻肚山複合型山崩 (齊柏林拍攝，2009)



泰源馬武窟溪岩坡崩滑 (李璟芳拍攝，2016)

1 研究背景簡介



子計畫主題

(1)林銘郎
地下水引致節理岩坡破壞之變形運動堆積特徵與監測整治技術之研究

(2)王泰典、張國禎、黃奉琦
先進測繪結合數位實境岩坡監測技術研發與應用

(3)羅佳明、周憲德、李璟芳
以岩坡單元探討降雨引致道路岩坡破壞風險分級與整治技術機制評估之研究

(4)黃文昭、洪汶宜
以物理試驗及數值模型探討不同尺度岩坡之整治技術與破壞機制關係

(5)李宏輝、邱雅筑
地震力作用下之道路岩坡破壞特徵暨整治技術之機制評估

(6)翁孟嘉、邱家吉
應用離散裂隙網絡模式於岩坡穩定分析與整治對策評估研究

(7)鐘志忠、曾國欣
多重時空間尺度監測技術融合於岩石邊坡預警與整治應用之研發

(8)郭治平
拌合提升地球物理調查方法判釋成效之邊坡穩定材料研發與驗證

現地調查

機制檢核

現場監測

簡化分析

物理現象

1.潛勢評估
2.工程建議

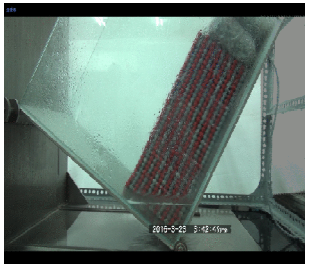
案例檢核

簡化模擬

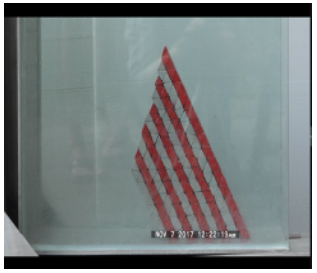
物理模型試驗

比對

數值模擬



順向坡

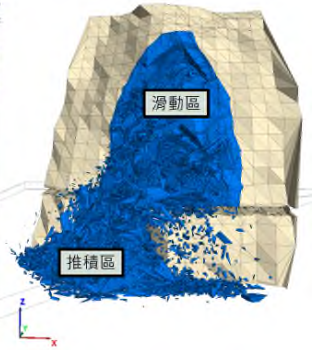


逆向坡

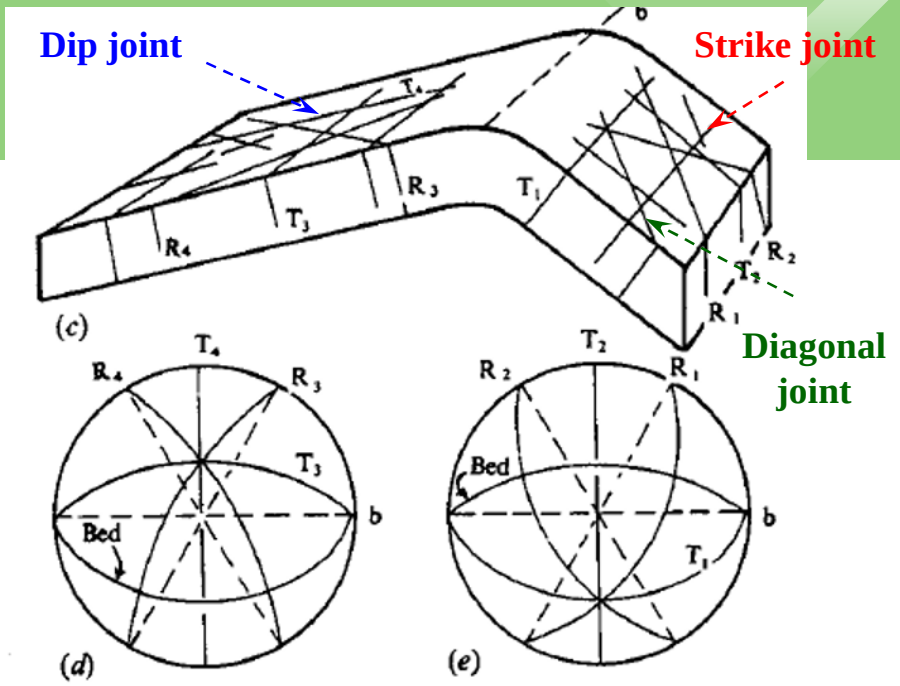


楔型破壞





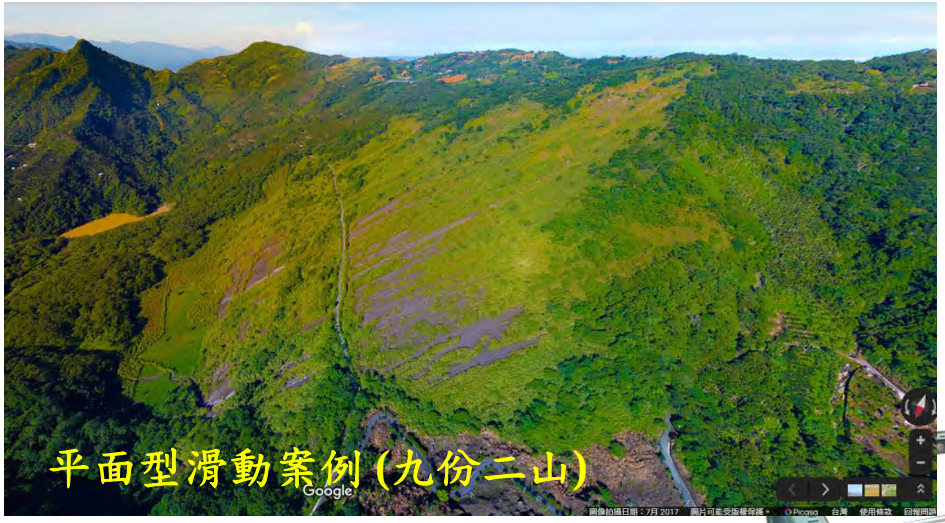

Intact rock
Discontinuity


Dip joint
Strike joint
Diagonal joint
(c)
(d)
(e)
Bed
Bed

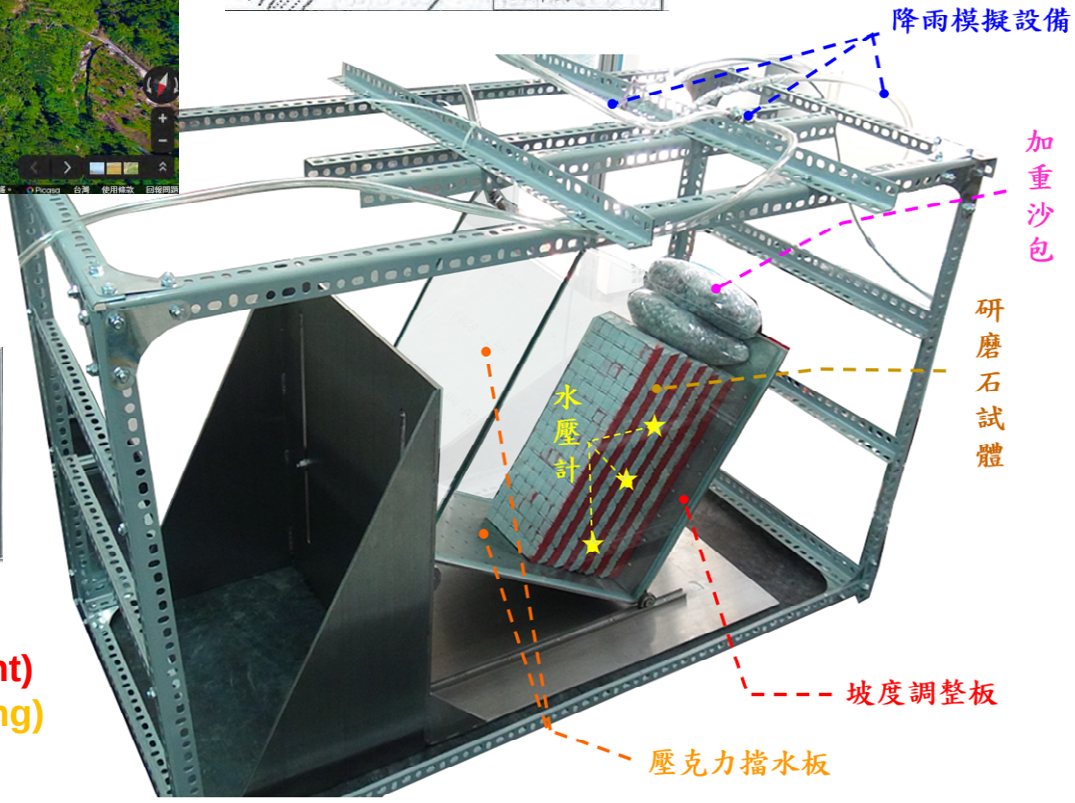


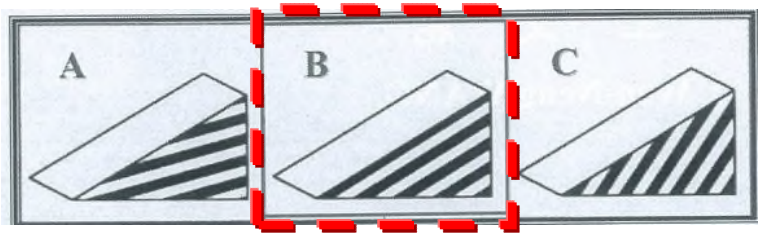

Anaclinal slope
2:38:56

順向岩坡



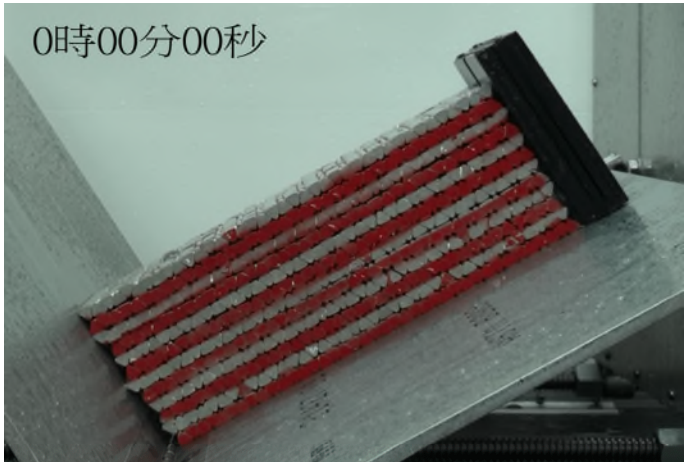


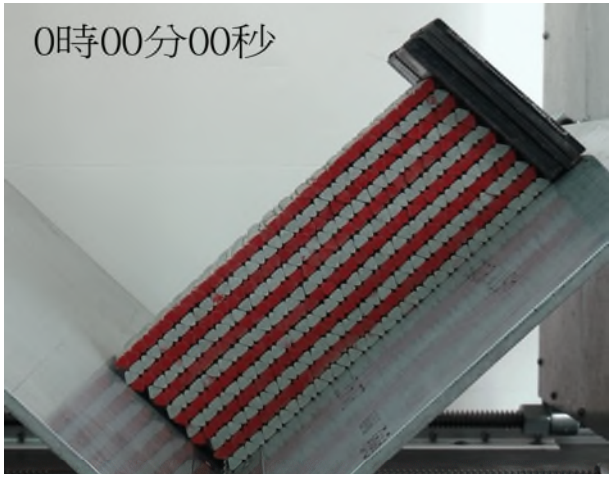


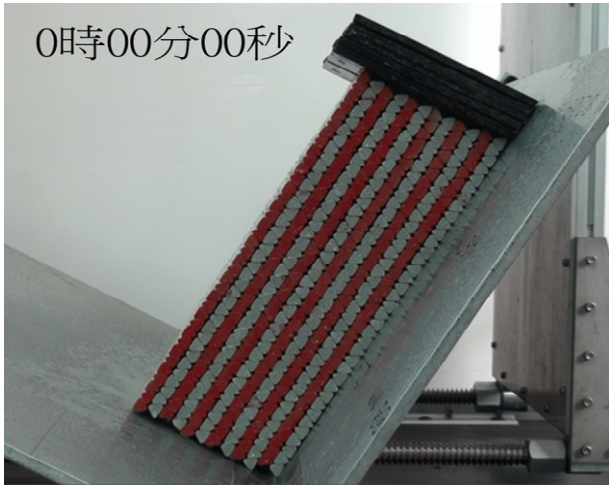


(A) 地形坡度 > 岩層傾角：趾部見光(Daylight)
(B) 地形坡度 = 岩層傾角：挫曲變形(Buckling)
(C) 地形坡度 < 岩層傾角：較為安全

三角柱狀物理模型-改變弱面傾角



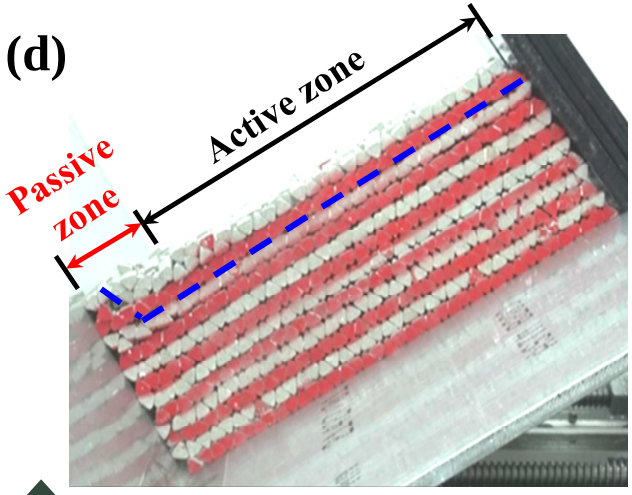


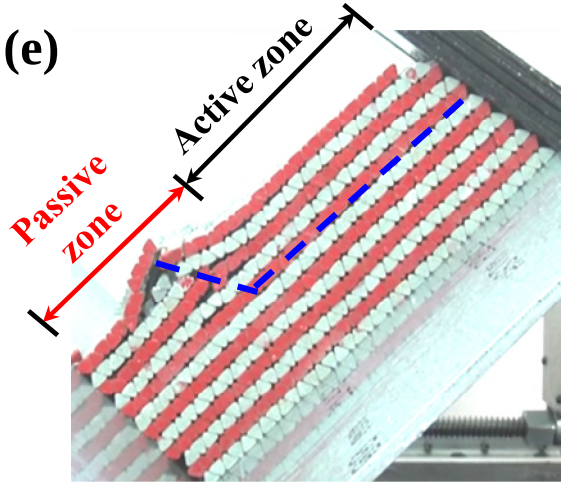


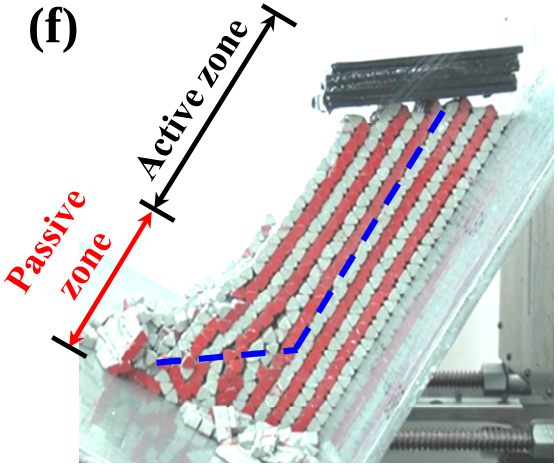
$\beta = 30^o$

$\beta = 45^o$

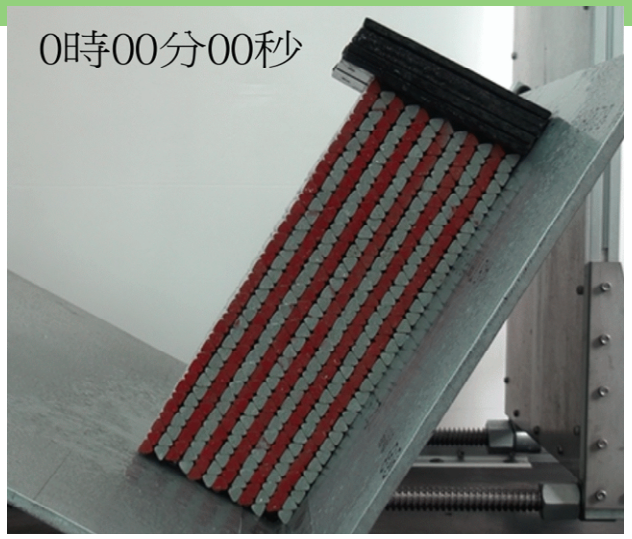
$\beta = 60^o$



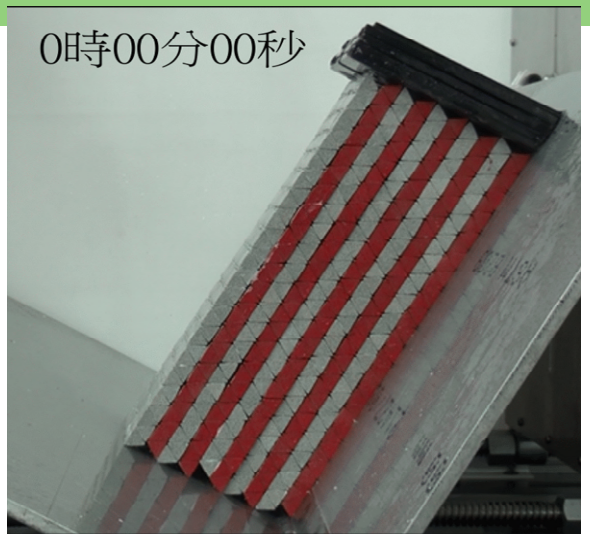




三角柱狀物理模型-改變弱面間距



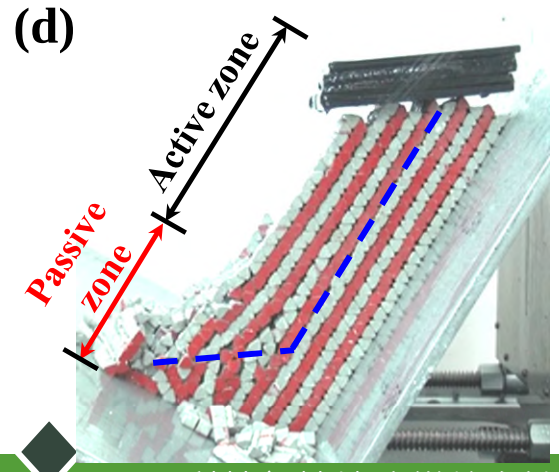
$S = 1.2cm$

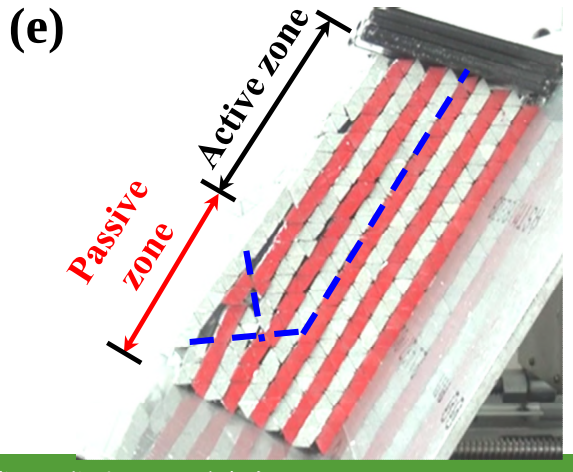


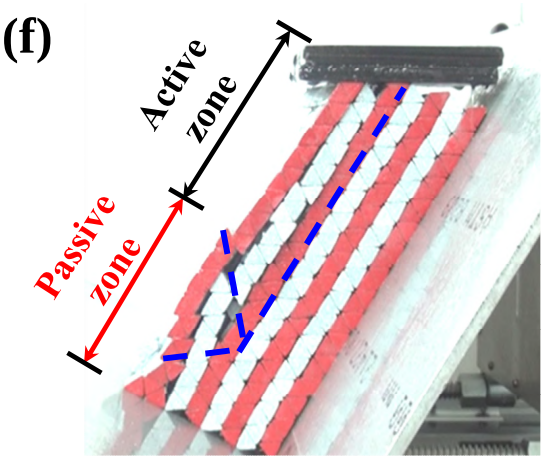
$S = 1.5cm$



$S = 2.0cm$

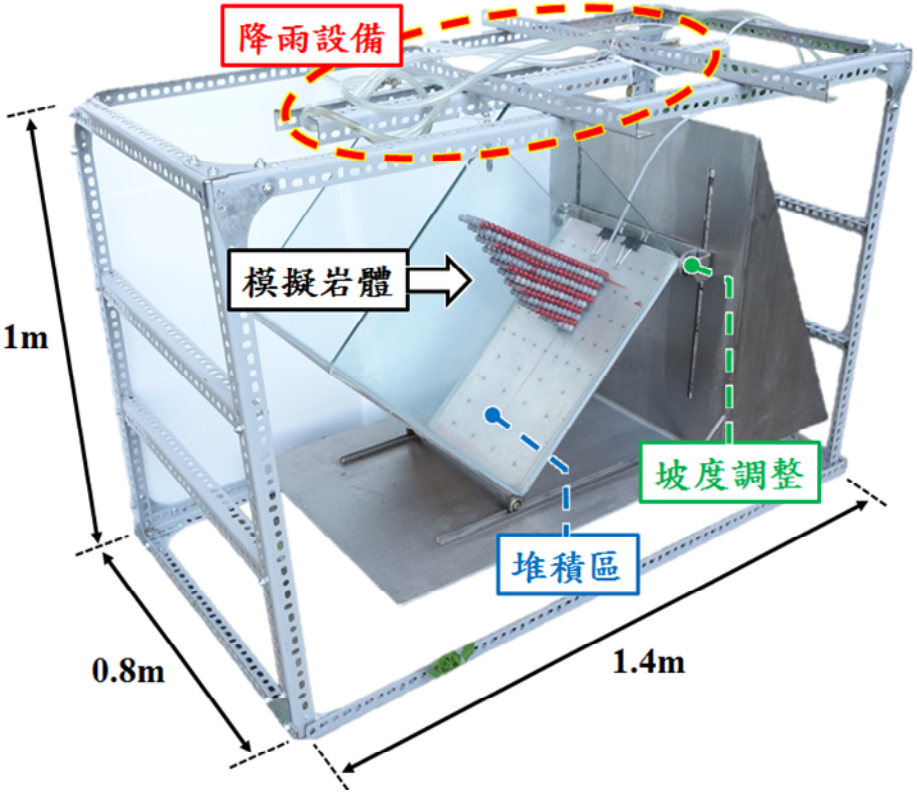


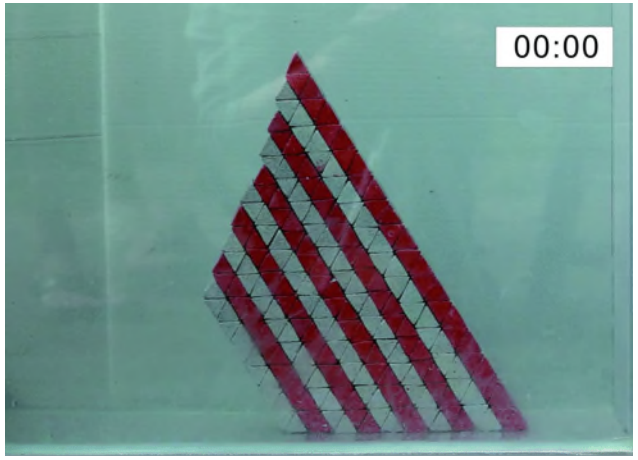




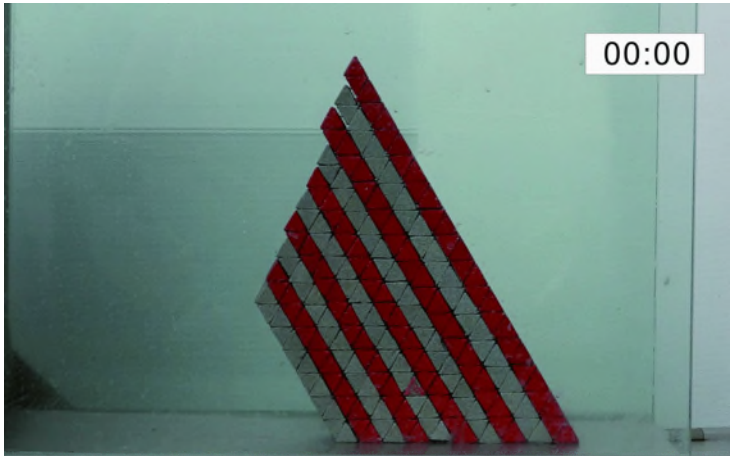
逆向坡



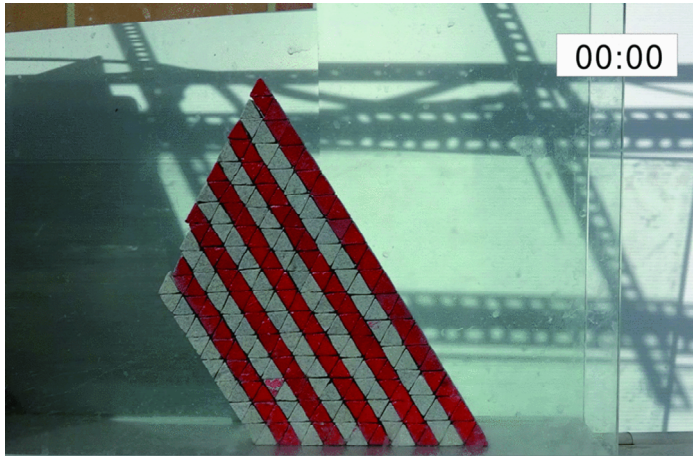




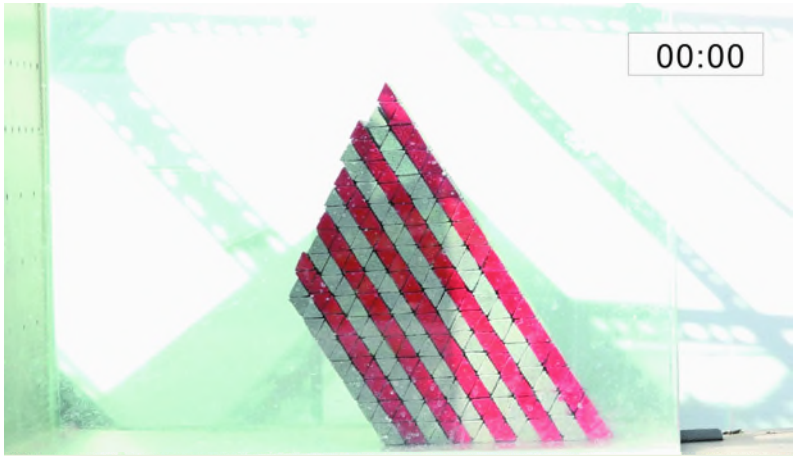
雨型-平均型



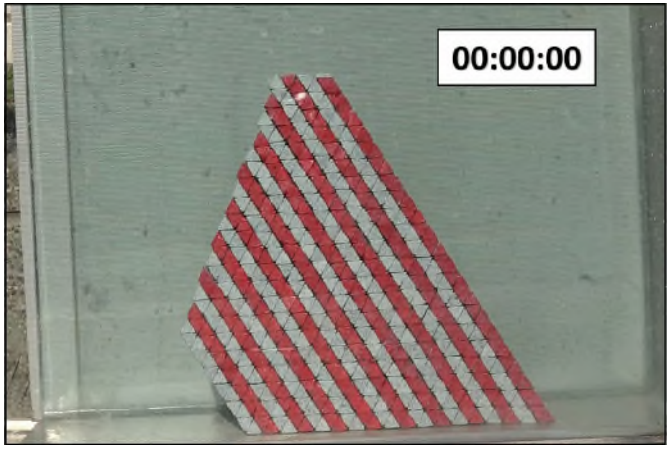
雨型-前鋒型



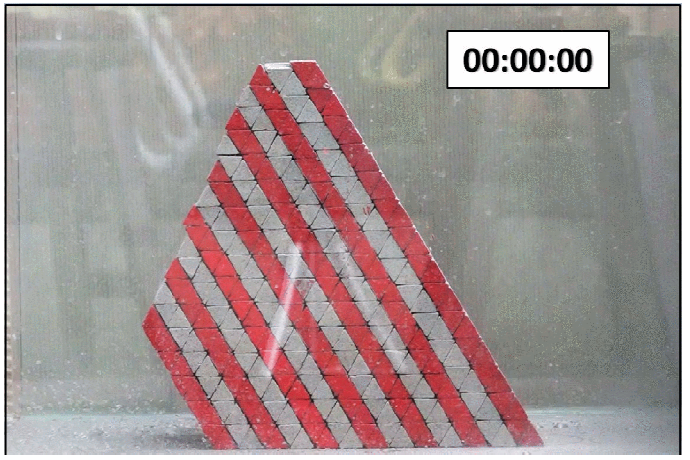
雨型-中鋒型



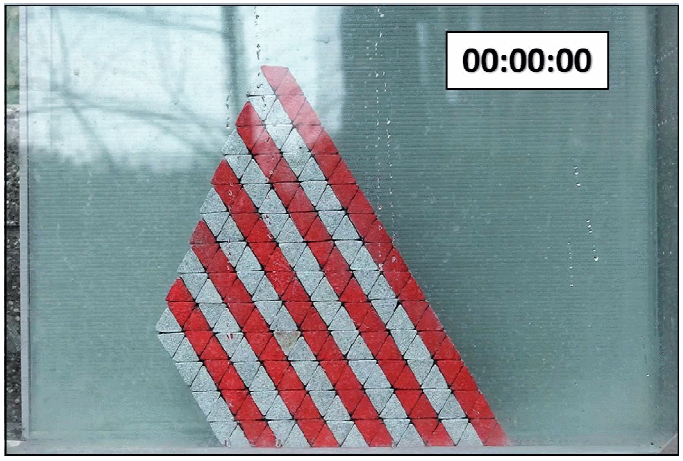
雨型-後鋒型



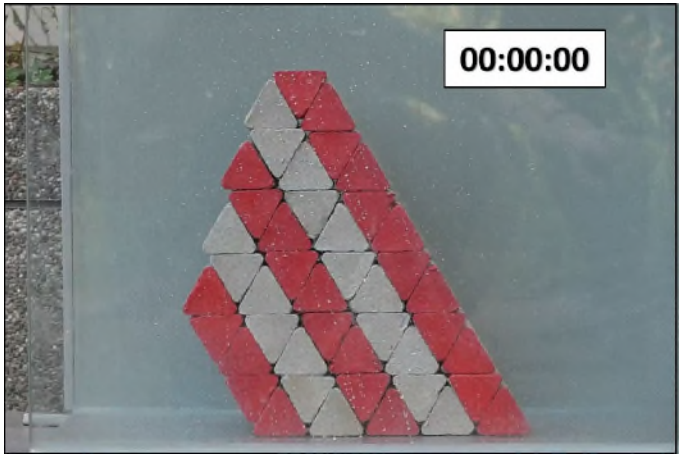
弱面_1cm_0.866cm



弱面_1.2cm_1.039cm



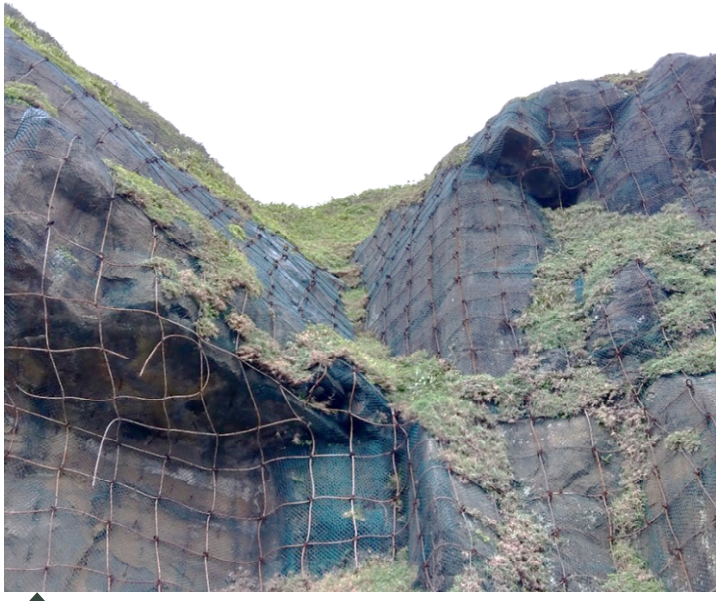
弱面_2cm_1.73cm

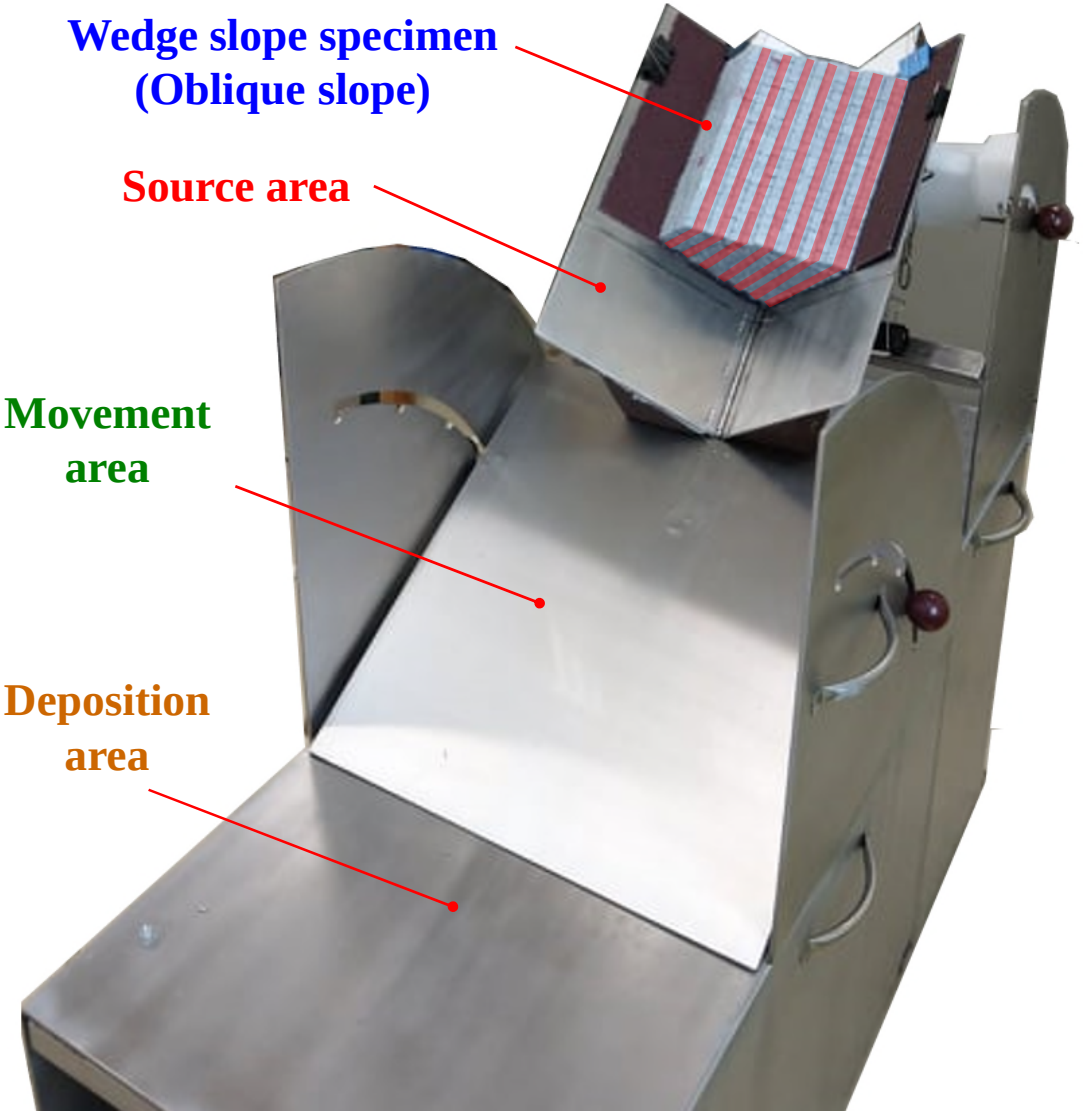


弱面_3cm_2.59cm

楔型岩坡



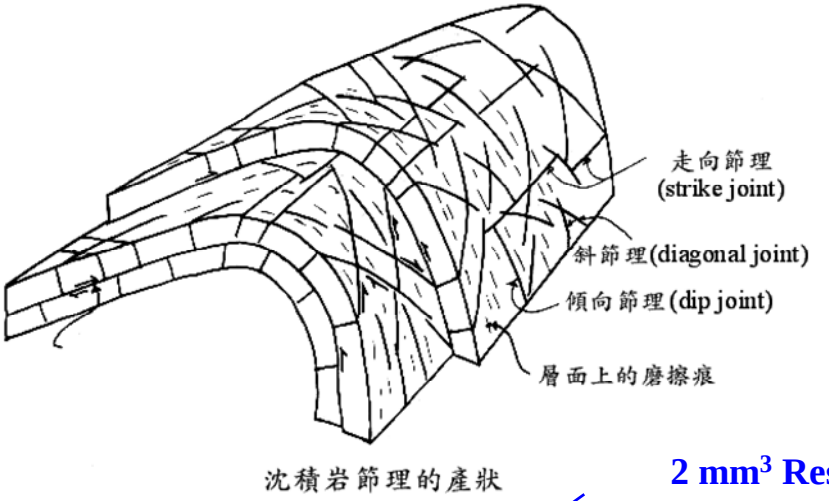



Wedge slope specimen
(Oblique slope)
Source area
Movement
area
Deposition
area

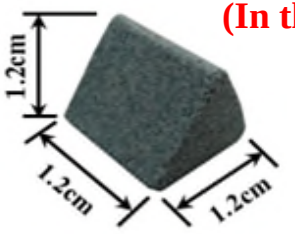
第二年-楔型岩坡







沈積岩節理的產狀

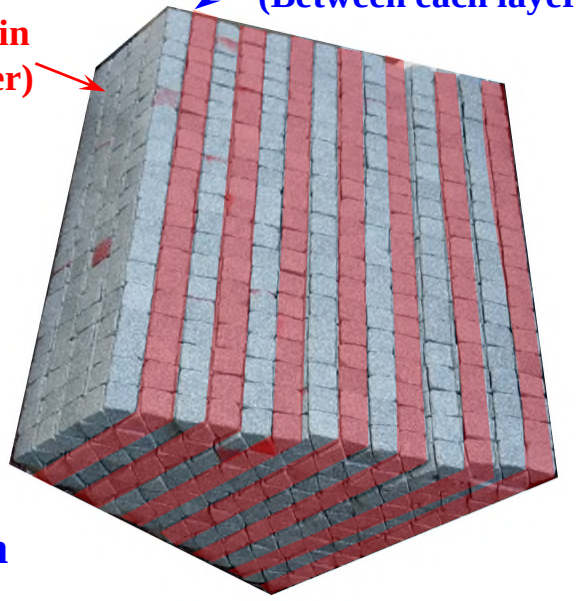




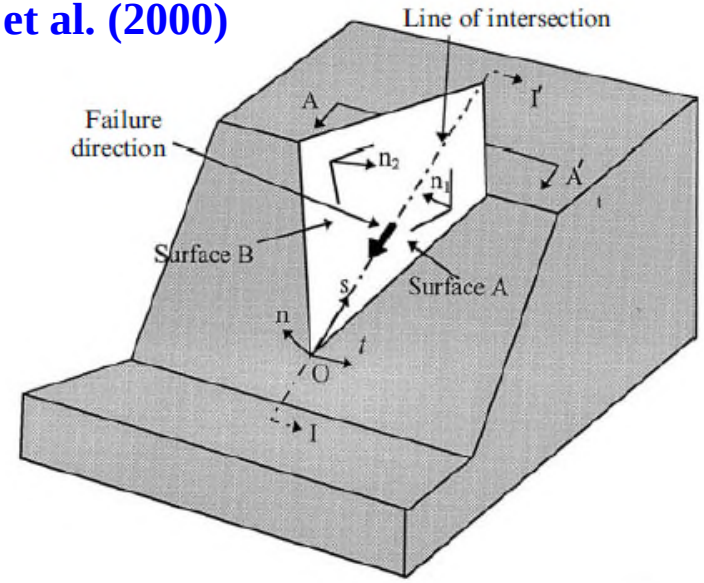
Resin

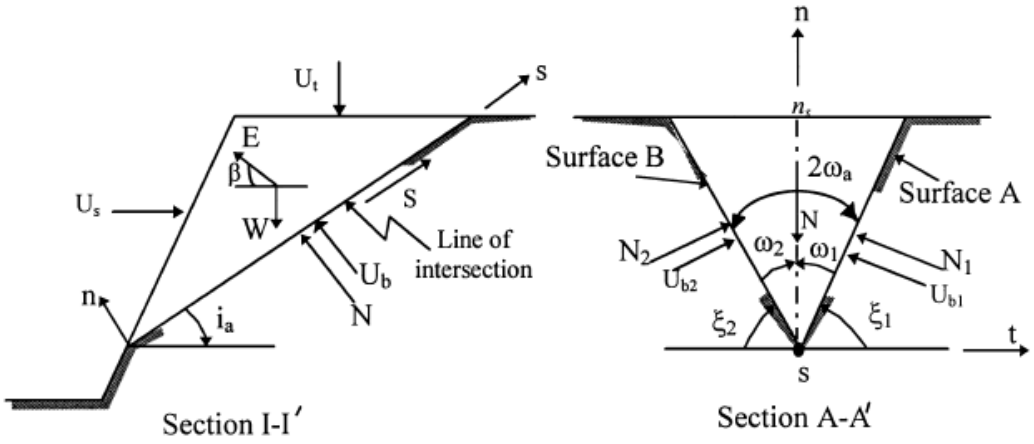
2 mm^3 Resin
(Between each layers)

8 mm^3 Resin
(In the layer)



Kumsar et al. (2000)

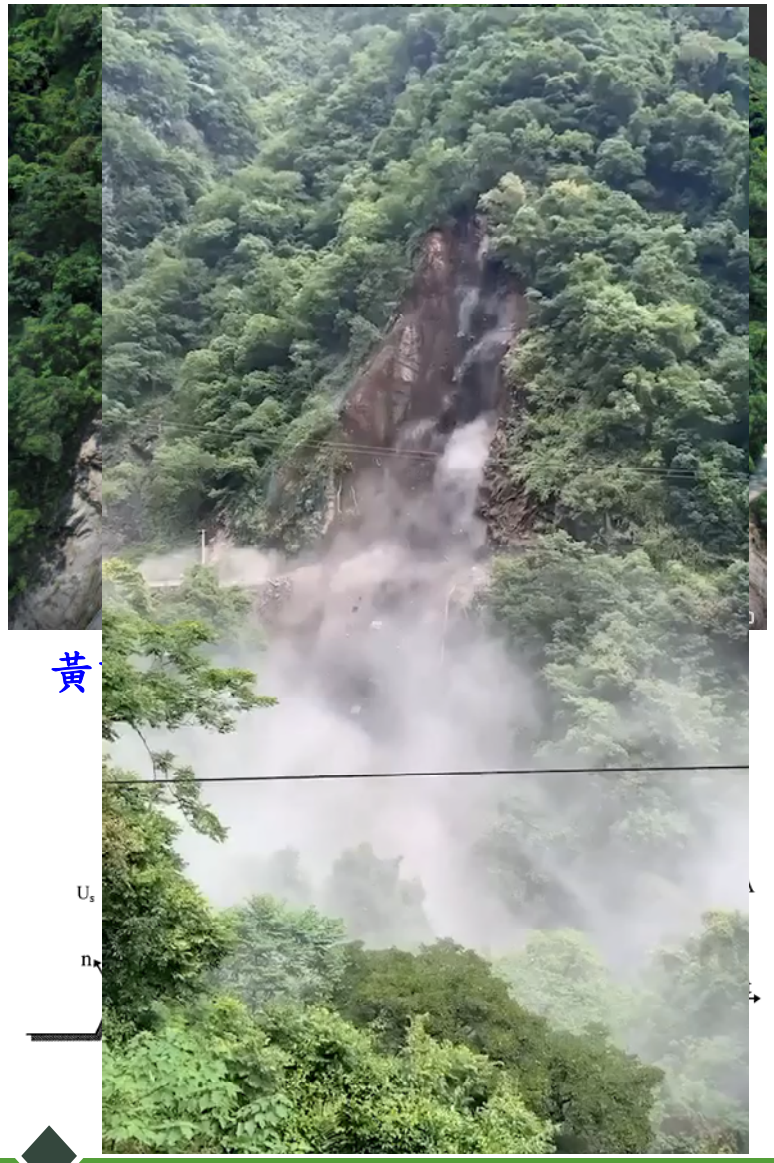




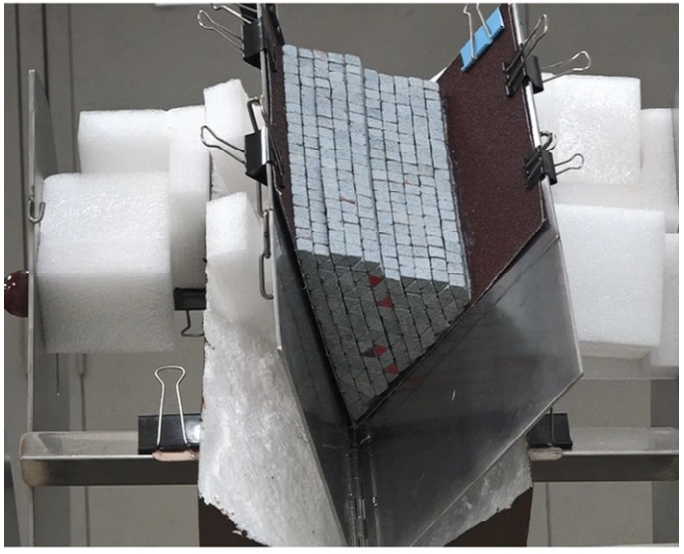
i_a	ω_1	ω_2	Oblique direction
40°	25°	25°	left
40°	45°	45°	right
40°	60°	60°	right
40°	75°	75°	left
50°-80°	45°	45°	right
70°	45°	45°	right
70°	25°	25°	right
60°	10°	45°	right

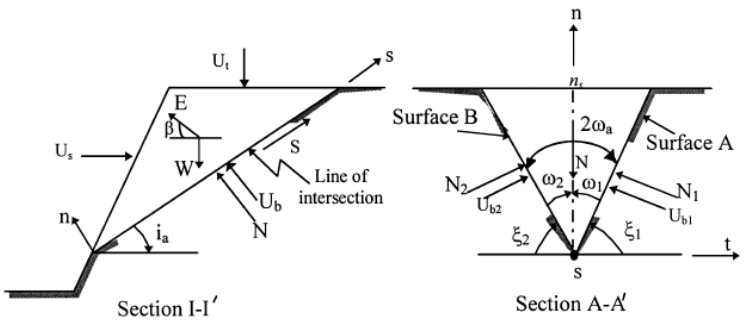
2 模型試驗設計與初步成果

i_a	ω_1	ω_2	Oblique direction
40˚	25˚	25˚	left

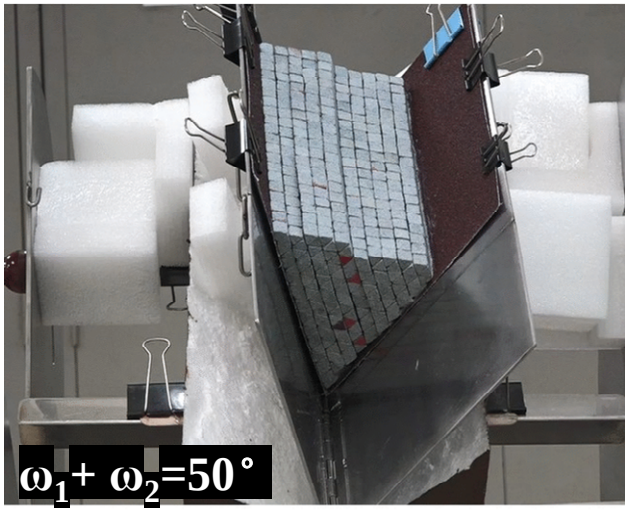


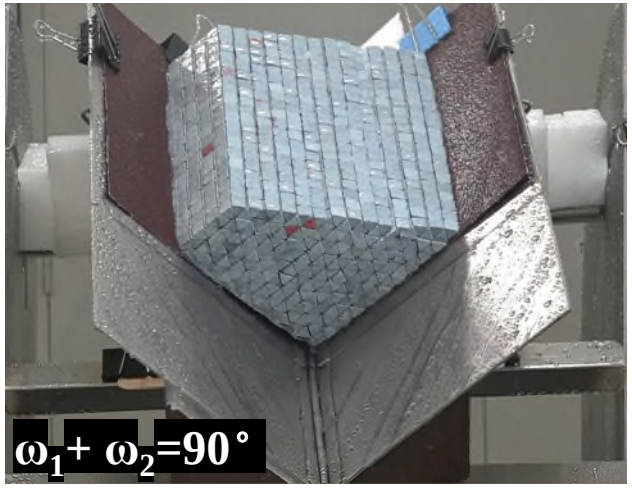


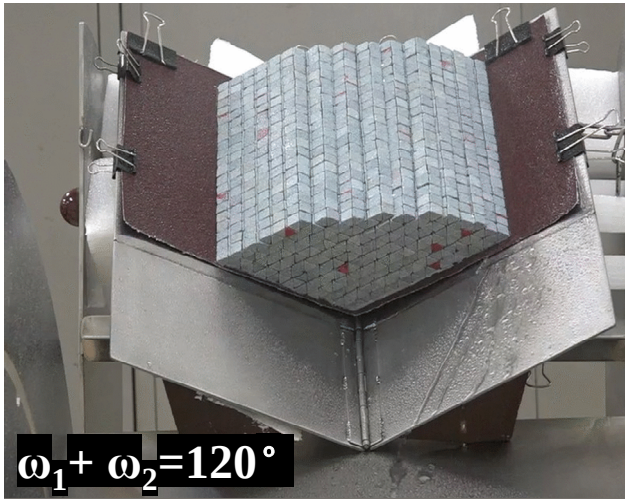


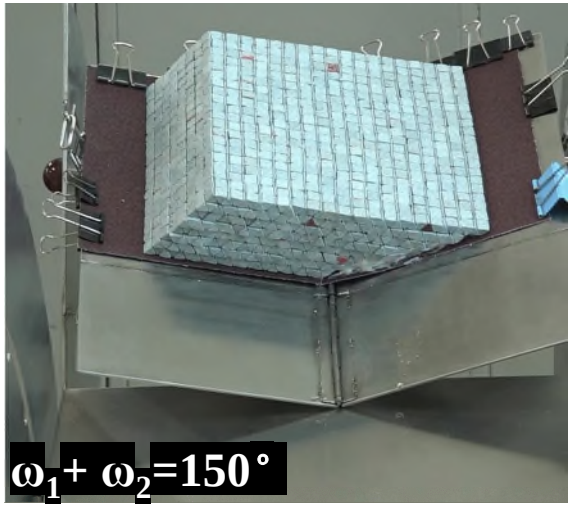


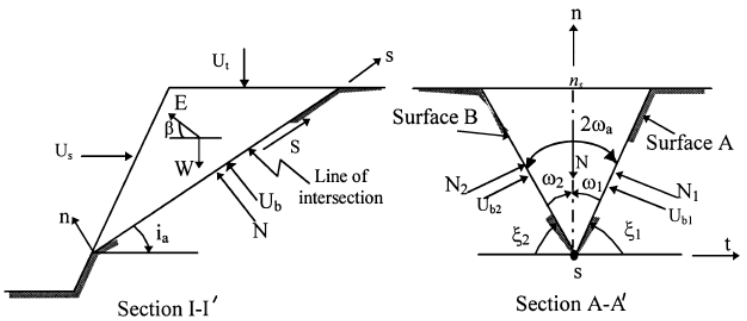
比較ω角度變化的影響 (i_a=40°)







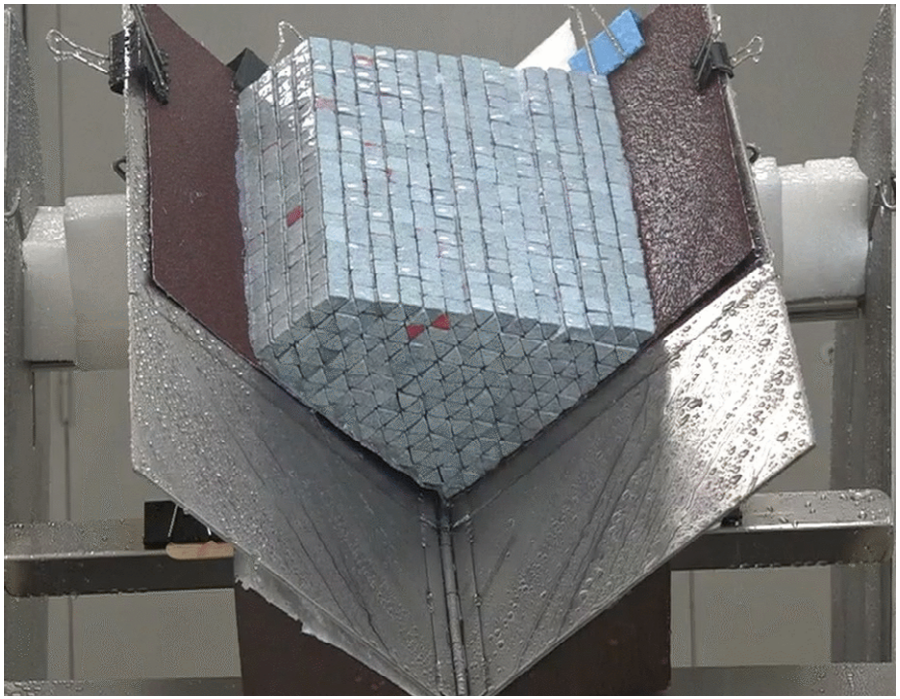




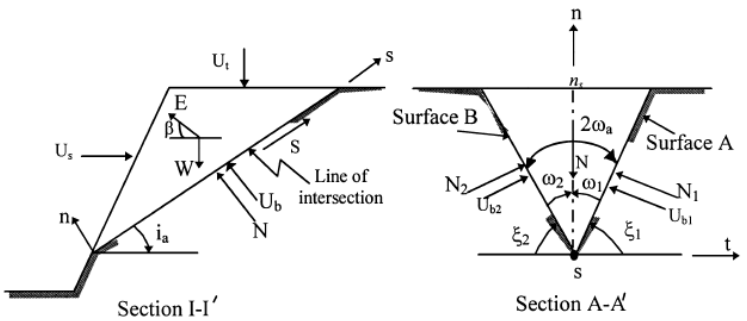
比較 i_a 角度變化的影響 (ω =90°)



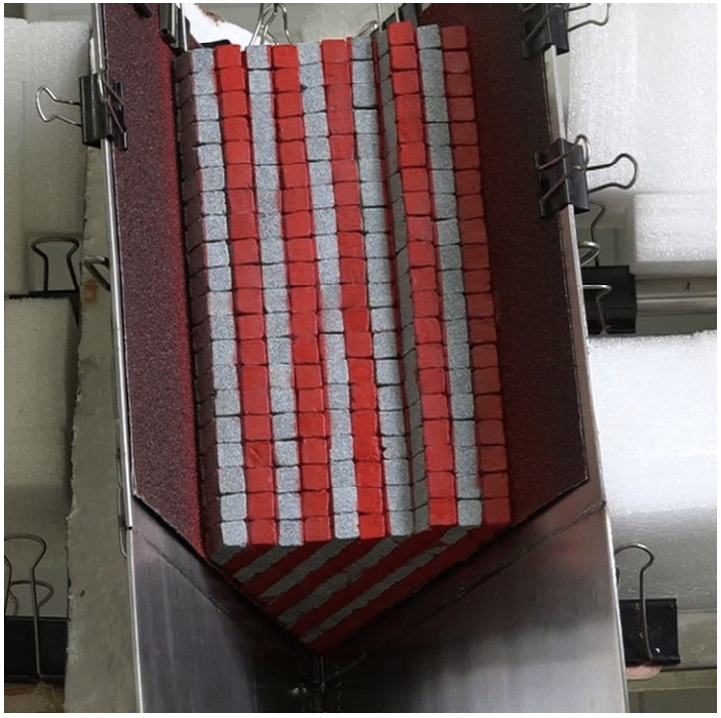
i_a	ω_1	ω_2	Oblique direction
70°	45°	45°	right



i_a	ω_1	ω_2	Oblique direction
40°	45°	45°	right



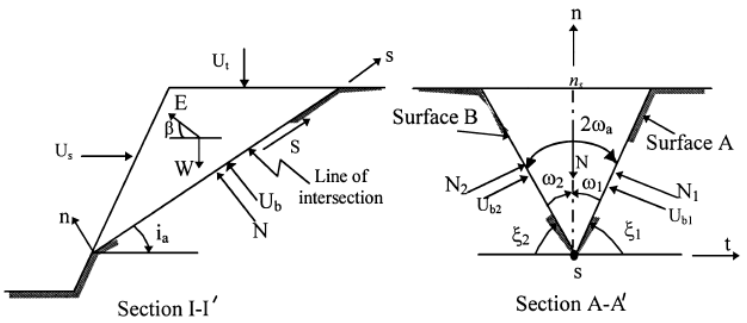
比較 i_a 角度變化的影響 (ω =50°)





i_a	ω_1	ω_2	Oblique direction
70°	25°	25°	right

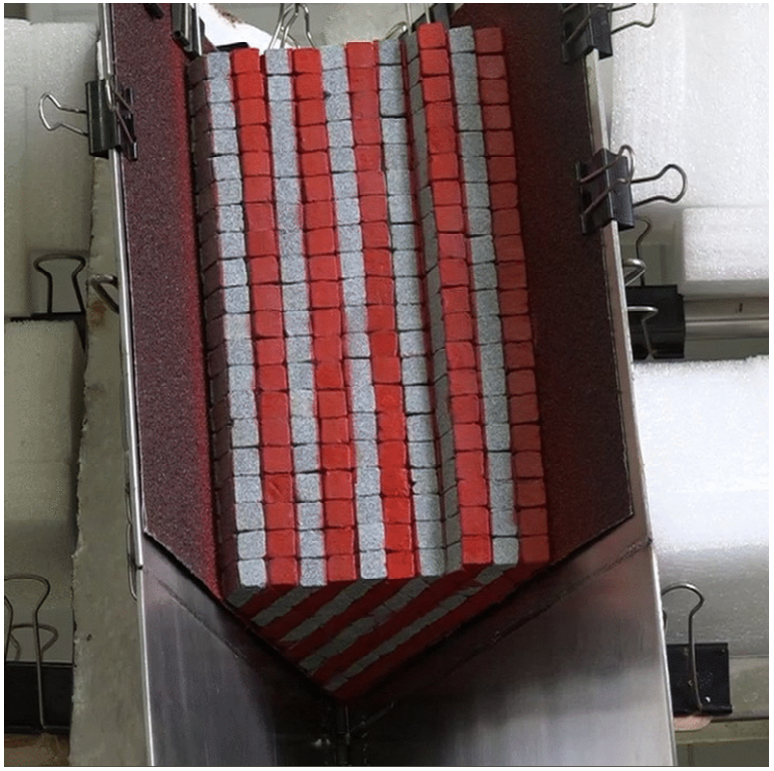
i_a	ω_1	ω_2	Oblique direction
40°	25°	25°	left



比較 ω_1與ω_2角度變化的影響



i_a	ω_1	ω_2	Oblique direction
60˚	10˚	45˚	right



i_a	ω_1	ω_2	Oblique direction
70˚	25˚	25˚	right

斜坡單元的優勢

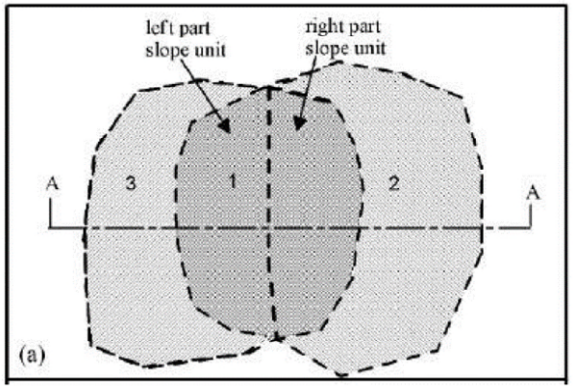
1.管理

2.分析

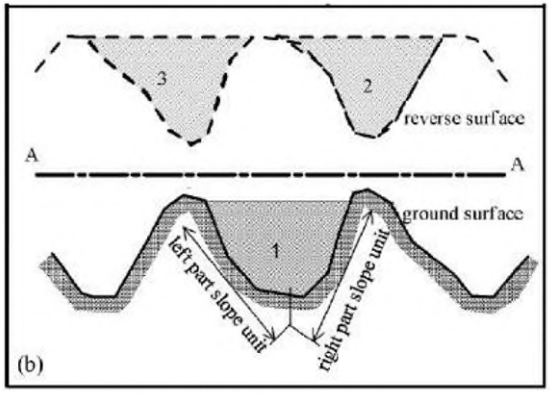
3.整合



烏來忠治里複合型山崩
(NCDR拍攝，2016)



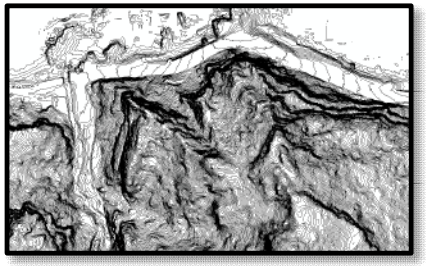
(Xie, 2004)





桃園合流部落岩坡崩滑
(李璟芳拍攝，2016)

岩坡單元劃設方法



Topographic maps



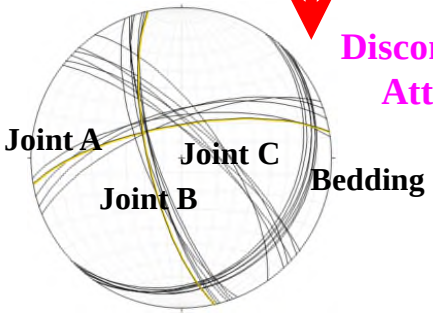
Geological maps



UAV images

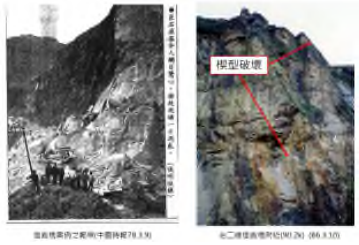


Field investigation

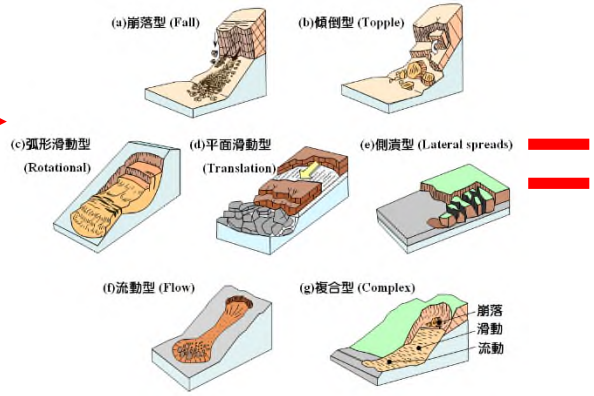


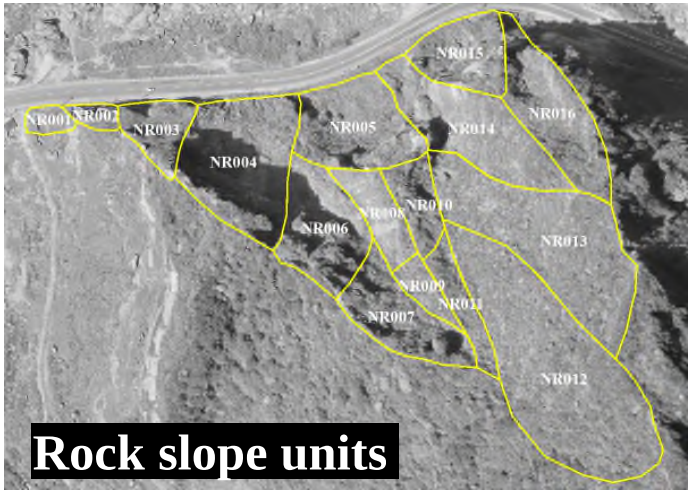
Discontinuity Attitude

Historical disaster

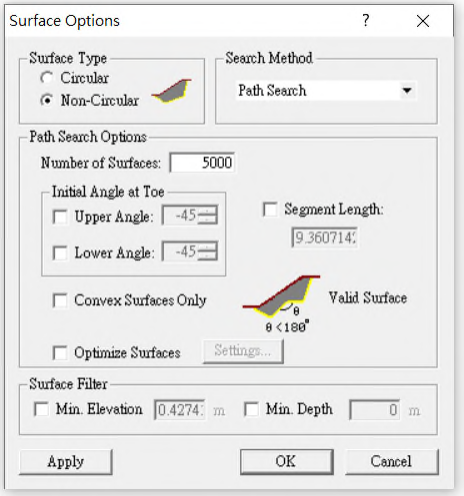


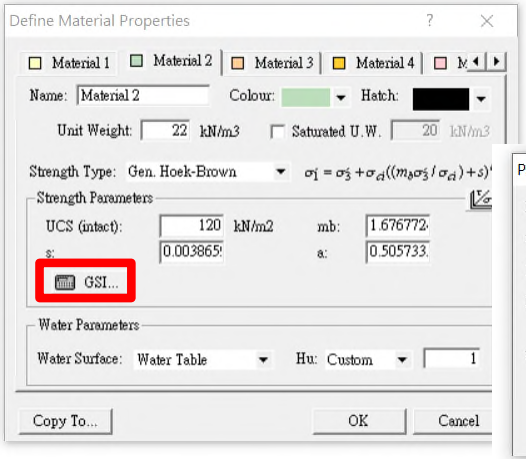
Landslide type
(Associated with rock slope failure)

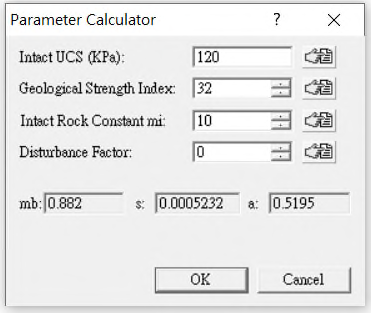


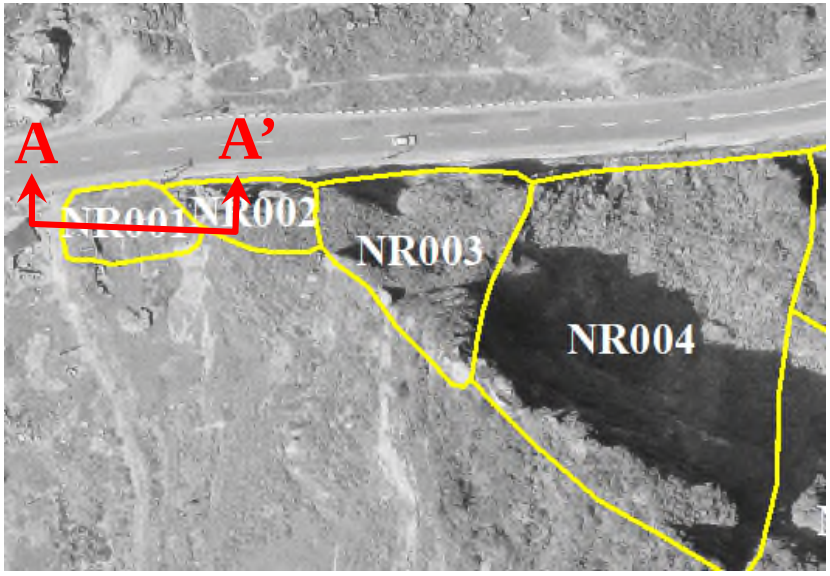


NR001 Rock slope unit



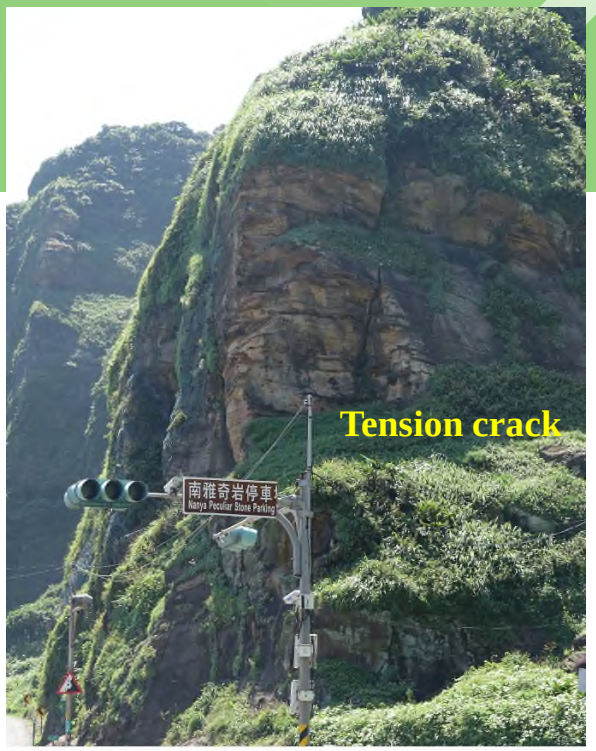


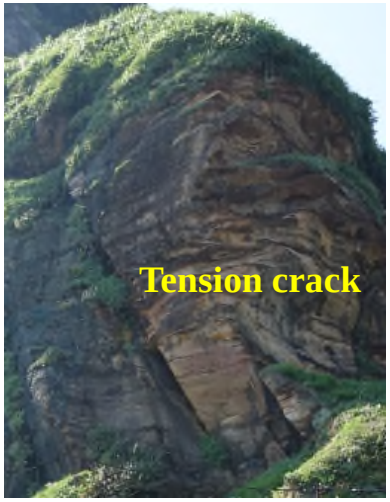


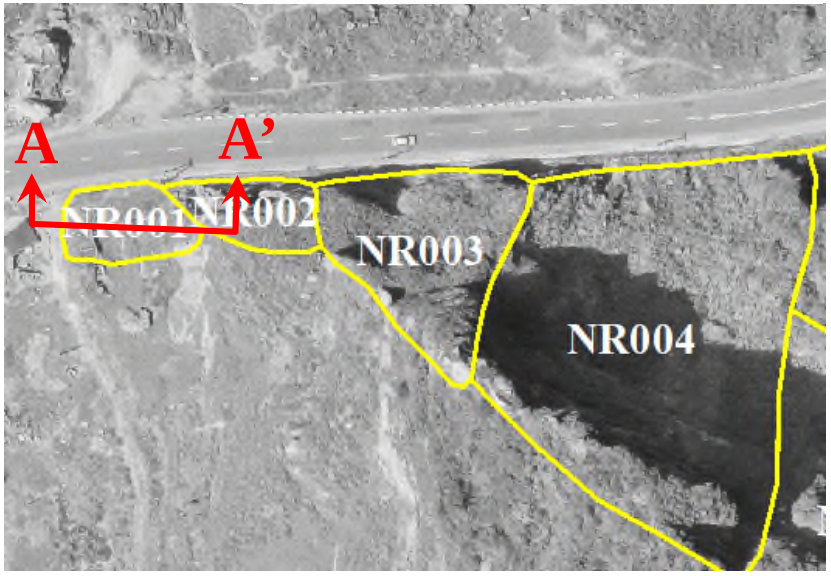


NR001 Rock slope unit

SLIDE





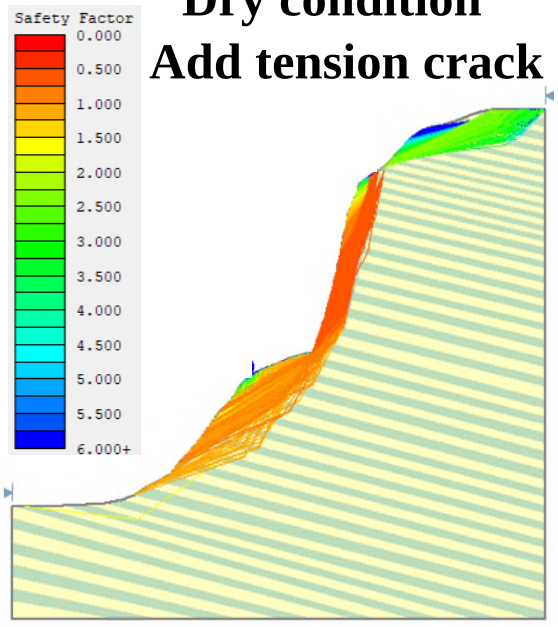


SLIDE

NR001 Rock slope unit

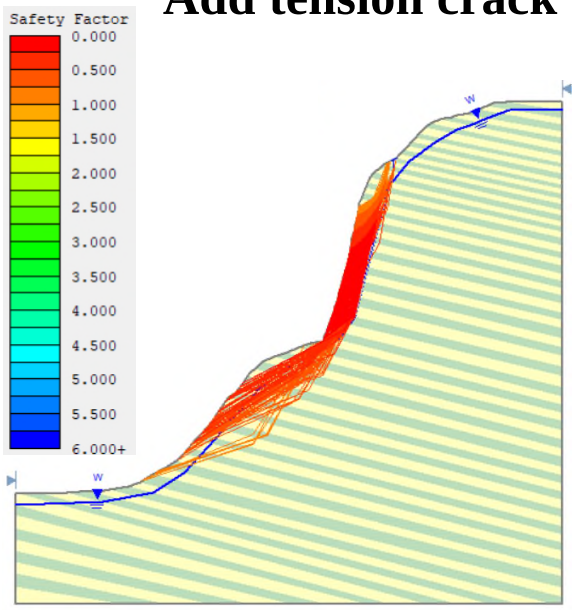
Dry condition

Add tension crack



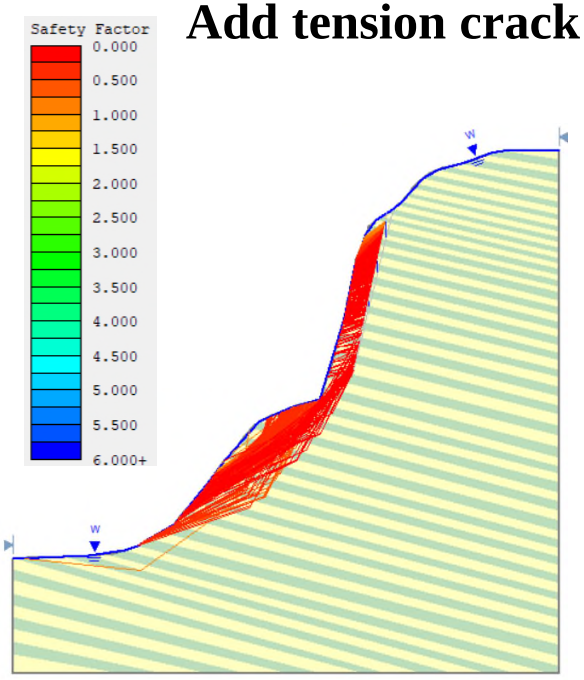
Add groundwater

Add tension crack

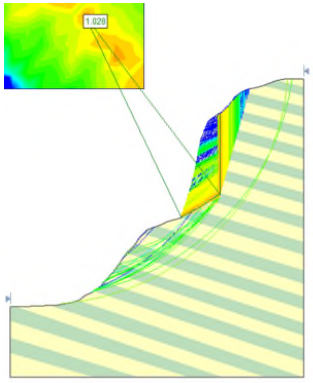


Full groundwater

Add tension crack



初擬各級潛勢劃定規則



岩坡單元穩定分析

＋



物理模型試驗歸納

高潛勢 (優先篩選)

中潛勢 (次要篩選)

低潛勢 (最後篩選)

高潛勢初步研判規則



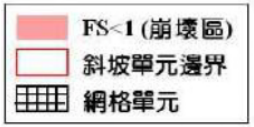
整個岩坡單元
平均FS<1



全面崩壞
(平均FS<1)
(整個岩坡單元
>50%之FS<1)



下邊坡崩壞 (平均FS<1)
(岩坡單元下半部>30%之FS<1)



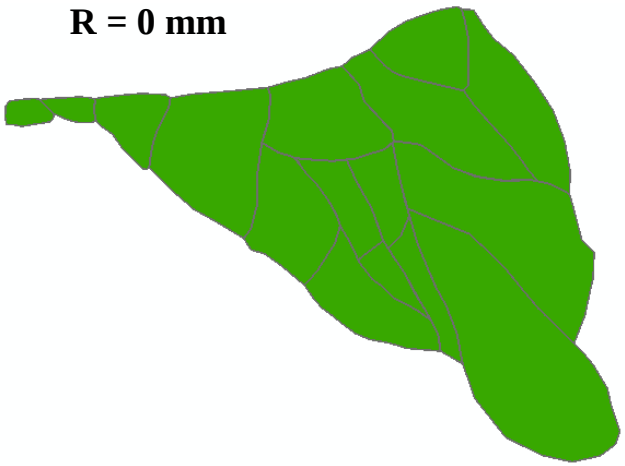
＋ 且50%楔型岩坡達:
I_a>40 °
ω_i>45 °
坡趾透空

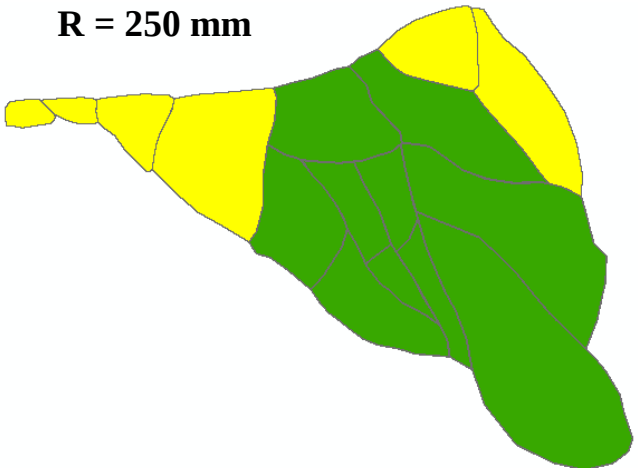
整個岩坡單元平均FS<1.5
局部崩壞 (整個岩坡單元>50%之FS<1.5)
下邊坡平均FS<1.5 (下半部>30%之FS<1.5)

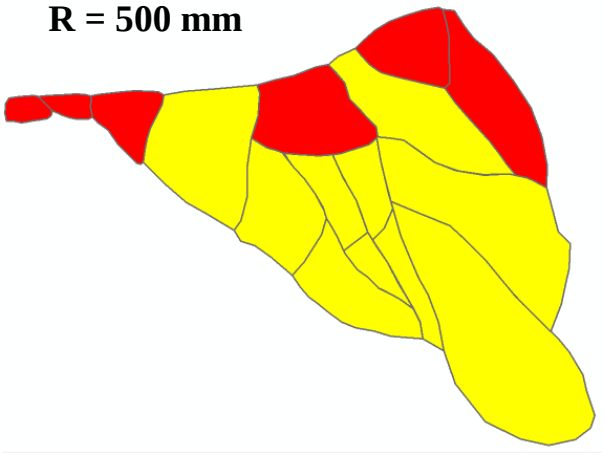
＋ 且30%楔型岩坡達:
I_a>30 °
ω_i<45 °
坡趾透空

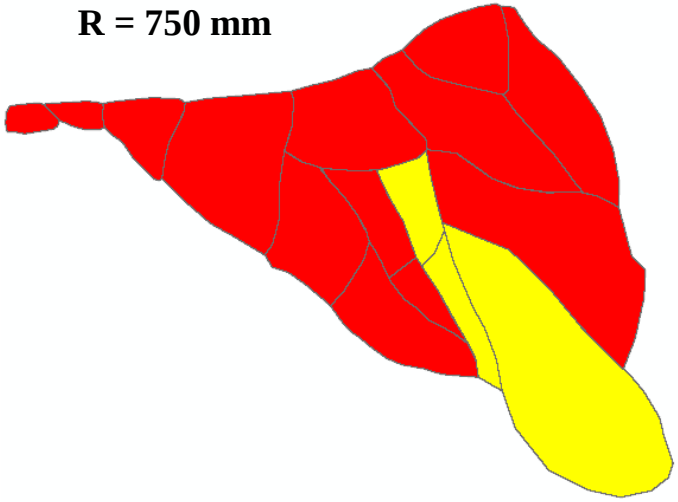
整個岩坡單元平均FS<2.0
局部崩壞 (整個岩坡單元>50%之FS<2.0)
下邊坡平均FS<2.0 (下半部>30%之FS<2.0)

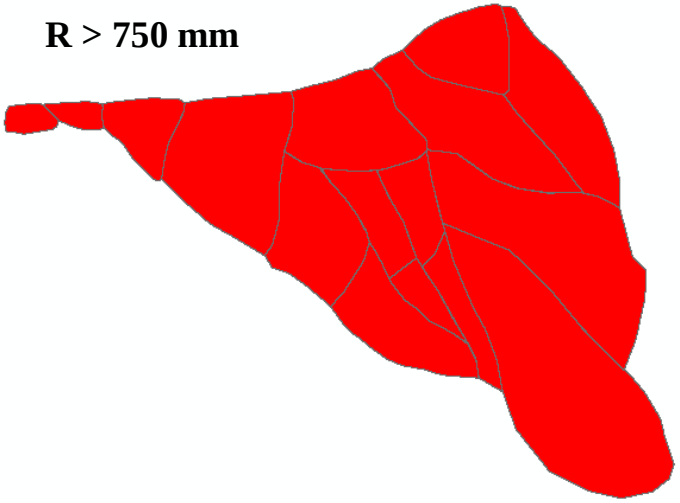
＋ 且30%楔型岩坡達:
I_a>30 °
ω_i<45 °
坡趾無透空











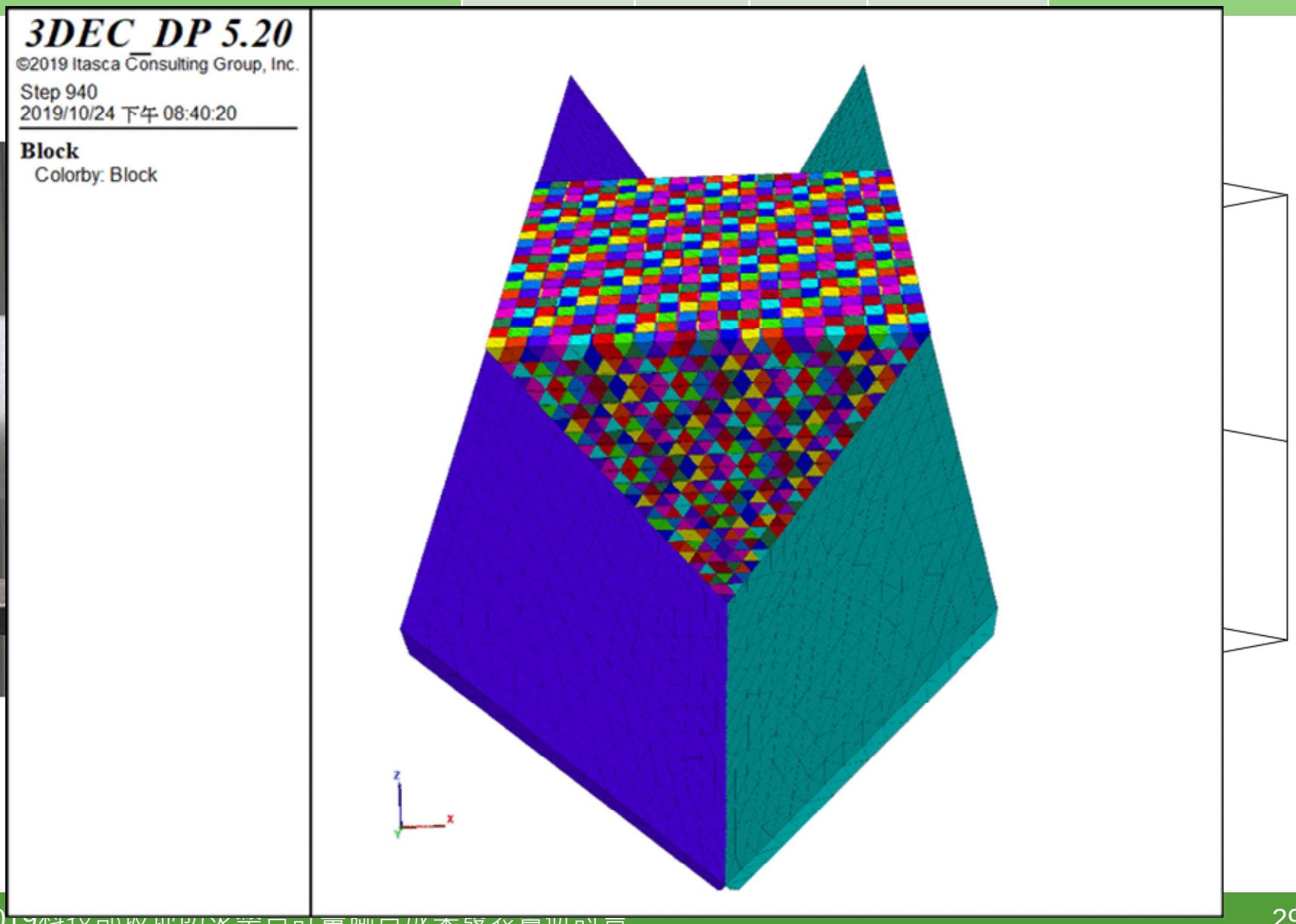
高潛勢

中潛勢

低潛勢

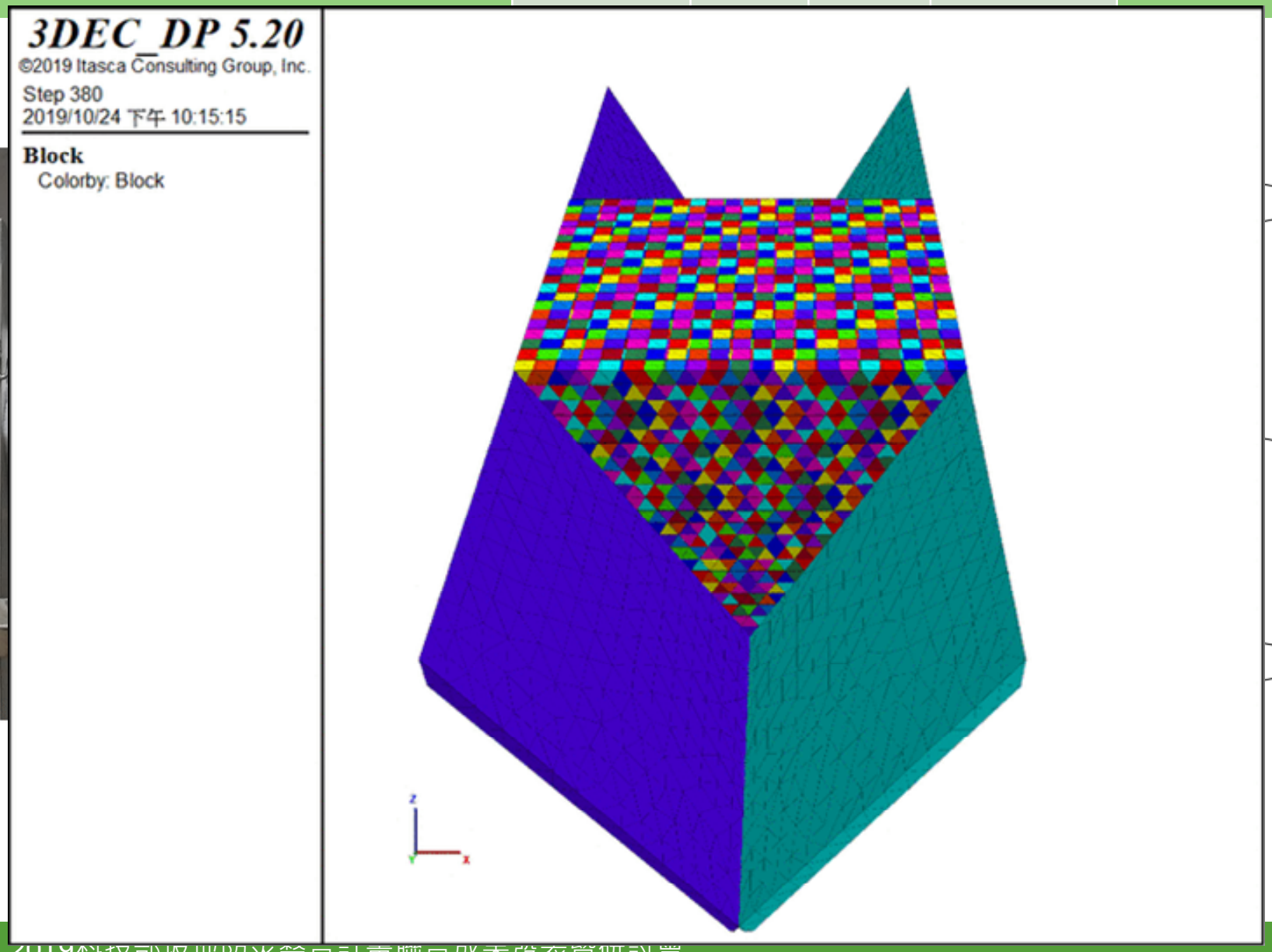
i_a	ω_1	ω_2	Oblique direction
40˚	25˚	25˚	left

3DEC



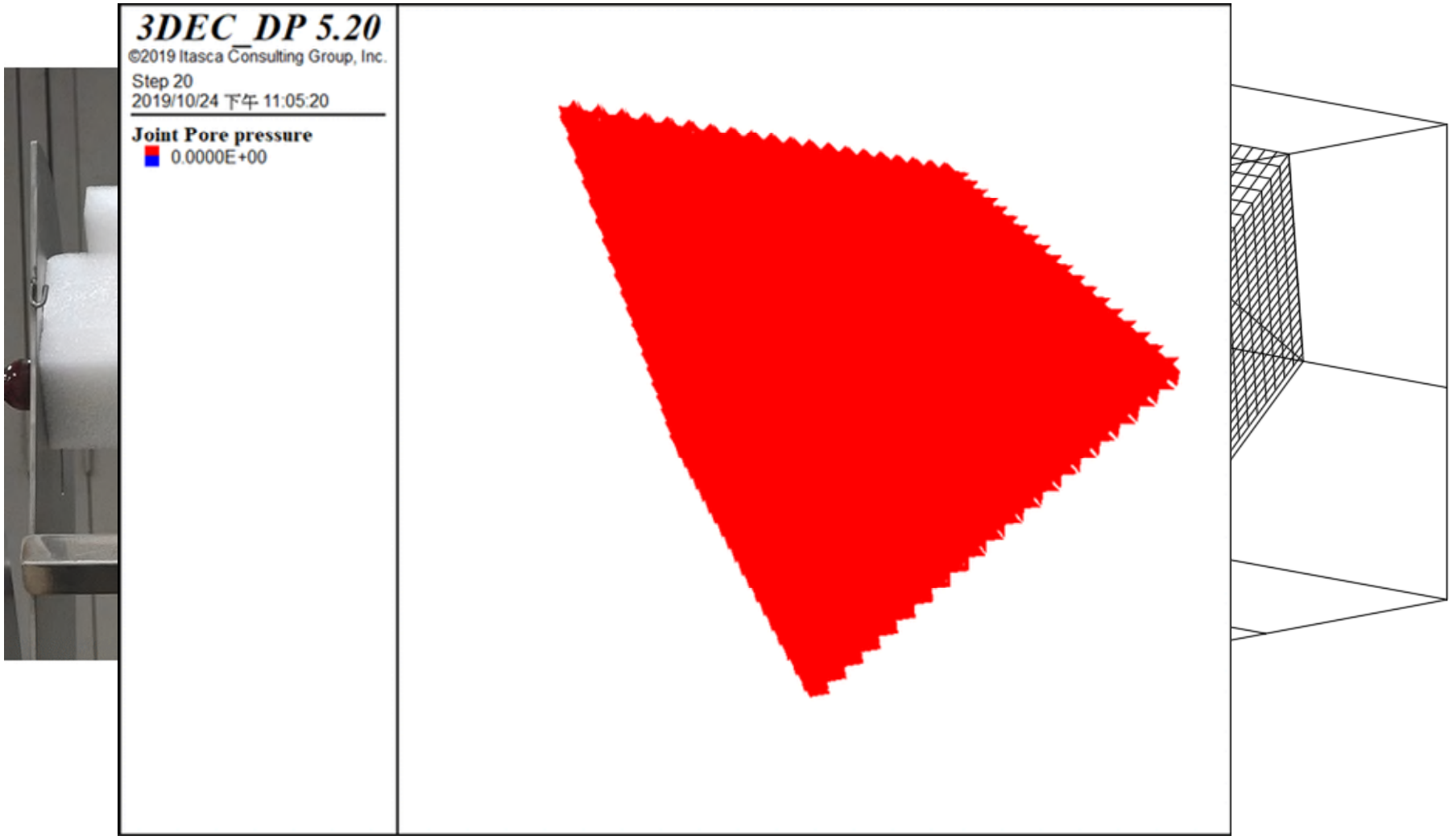
i_a	ω_1	ω_2	Oblique direction
40˚	25˚	25˚	left

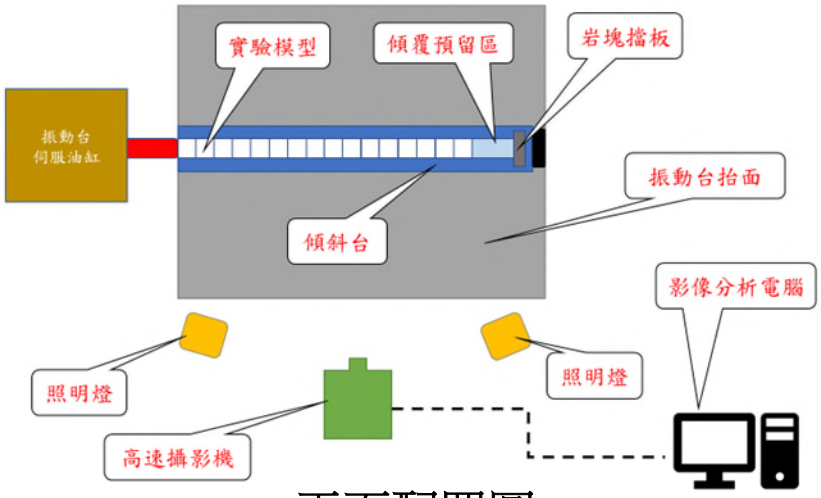
3DEC



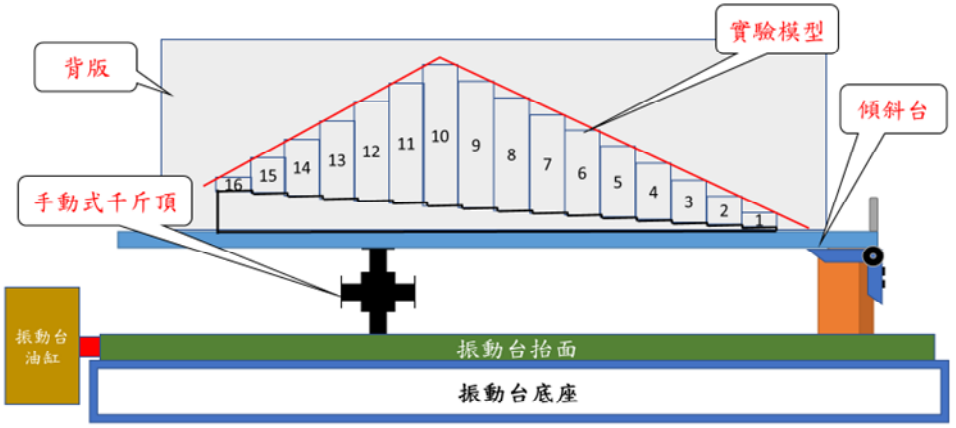
i_a	ω_1	ω_2	Oblique direction
40˚	25˚	25˚	left

3DEC

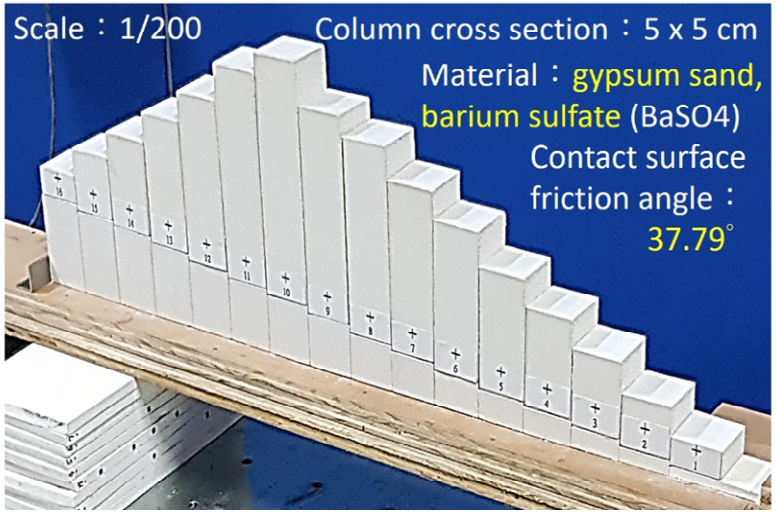




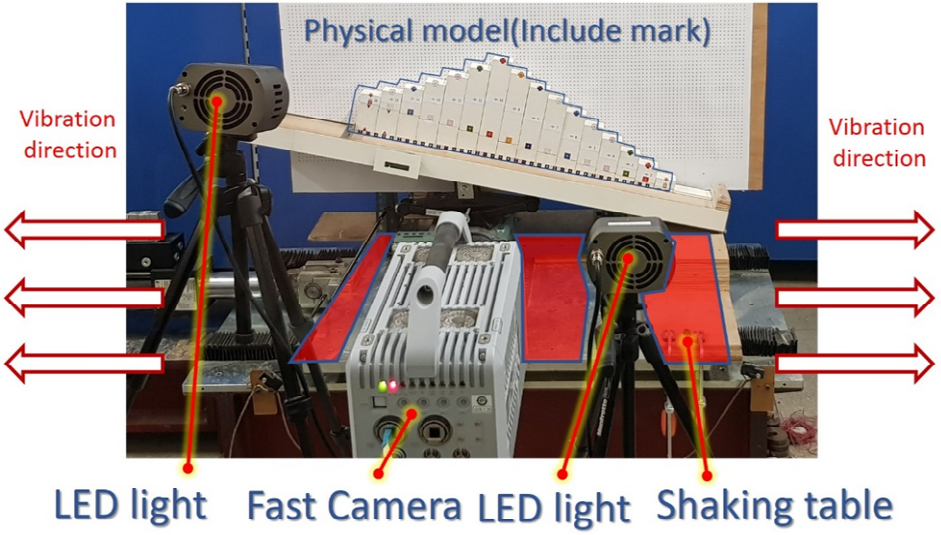
平面配置圖



立面配置圖

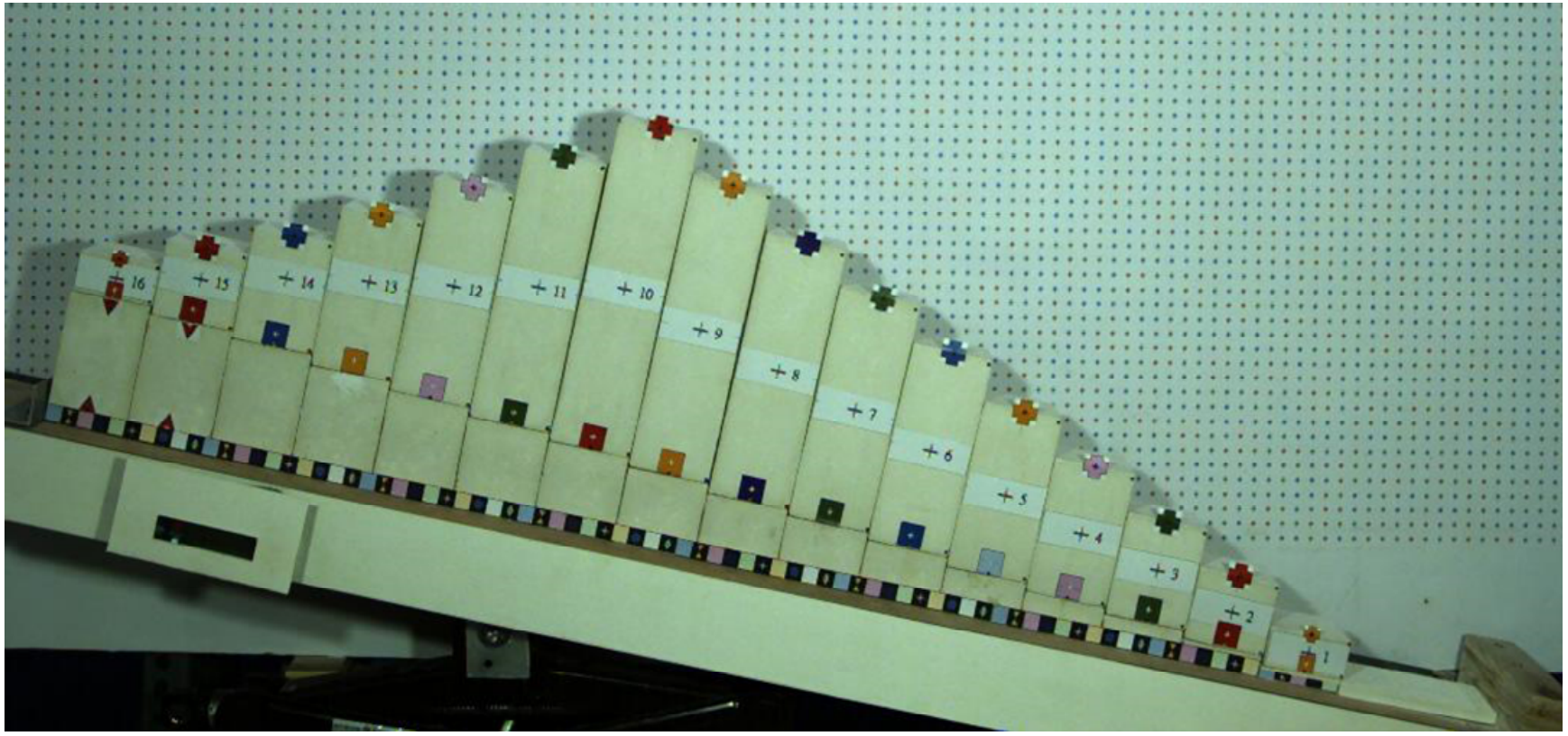


縮尺模型



實際試驗配置

◆Case S30($\psi_p = 12°$), PGA =0.48g, f = 4Hz

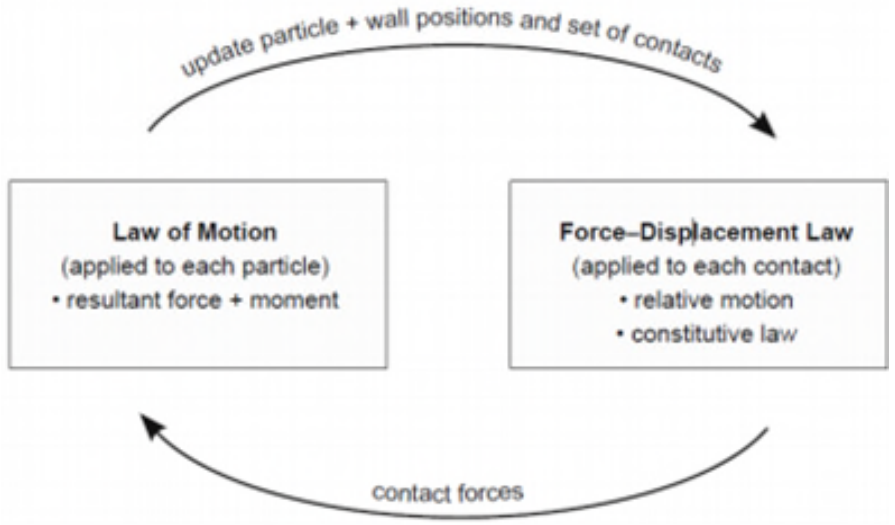


以離心機試驗達成簡化順向坡模型承受不同重力場之條件

以離散元素數值模型了解其內部應力之發展狀況



中央大學地工離心機

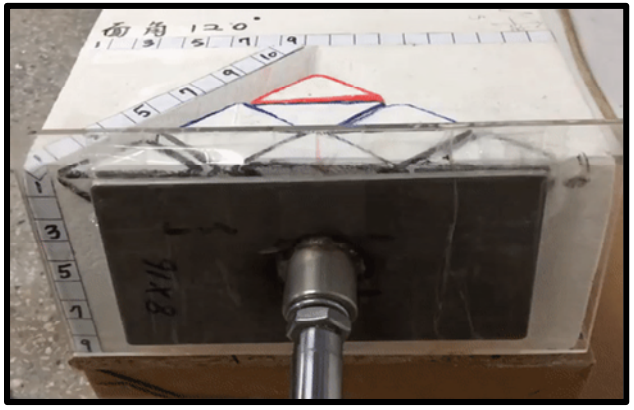


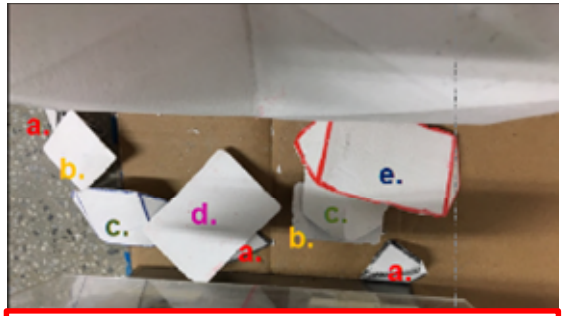
PFC3D 運算流程圖（PFC manual）

複合楔形塊體(試驗3) – 3DEC數值模擬

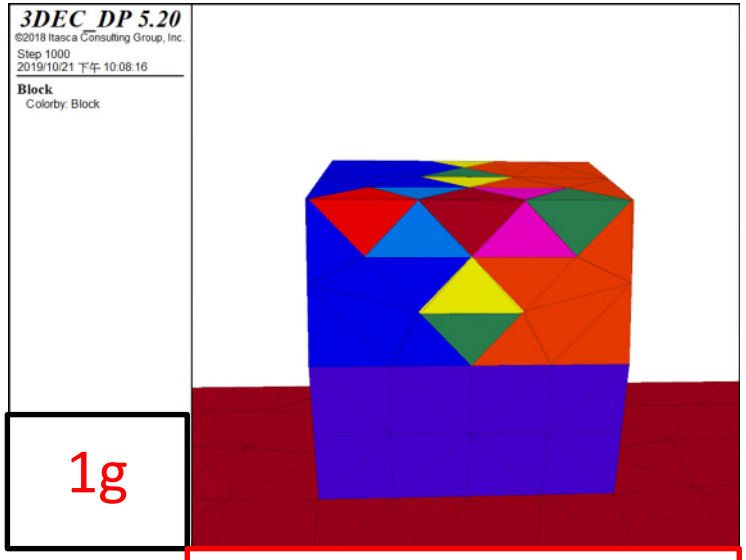
- 1g物理試驗 vs 數值模擬1g&40g



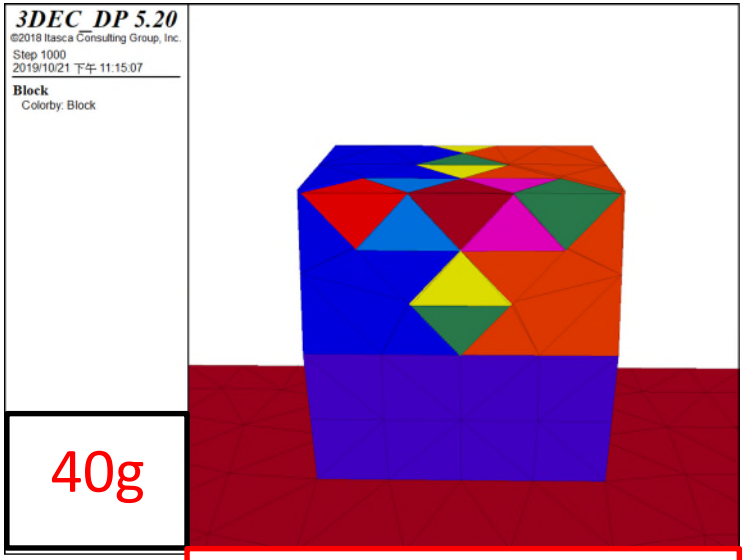




塊體崩落率≒100%

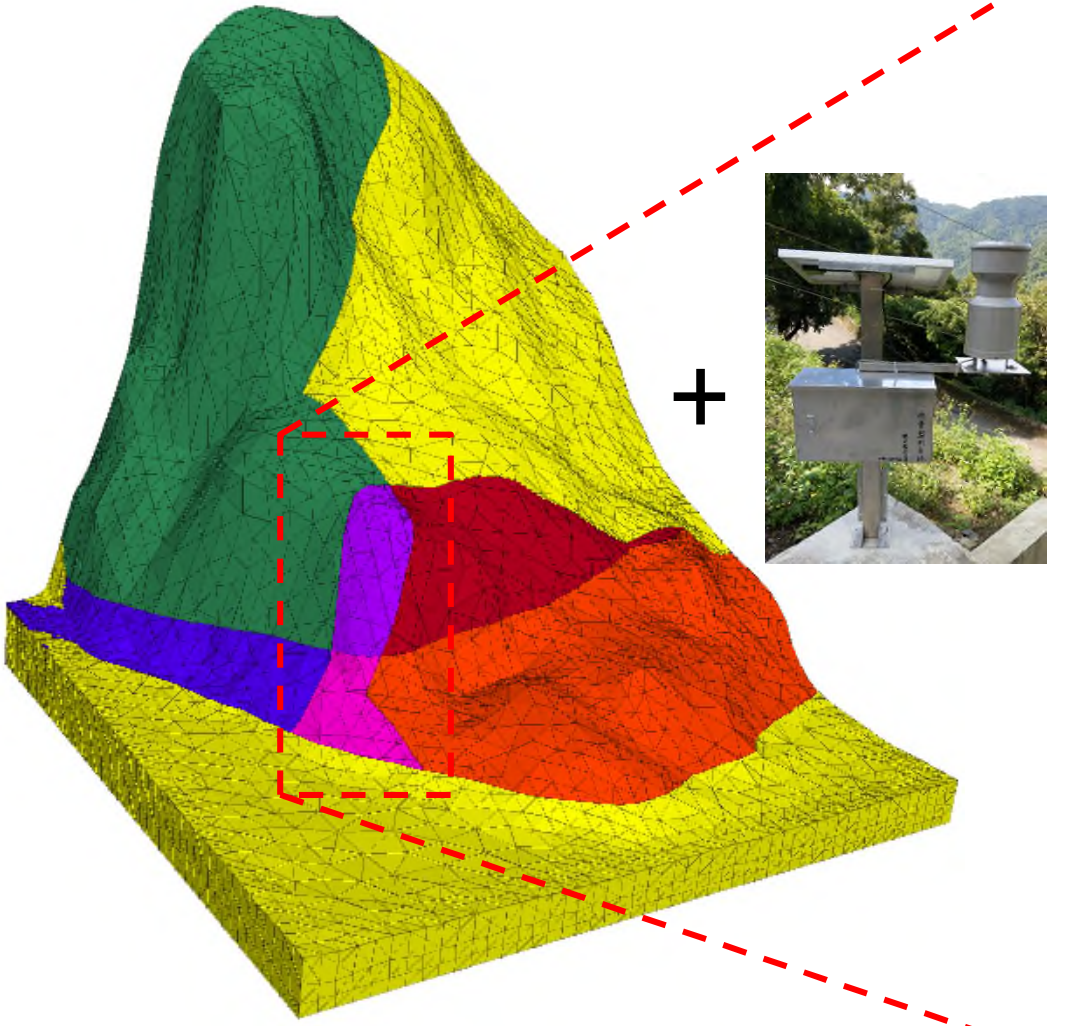


塊體崩落率≒100%



塊體崩落率≒100%

3DEC



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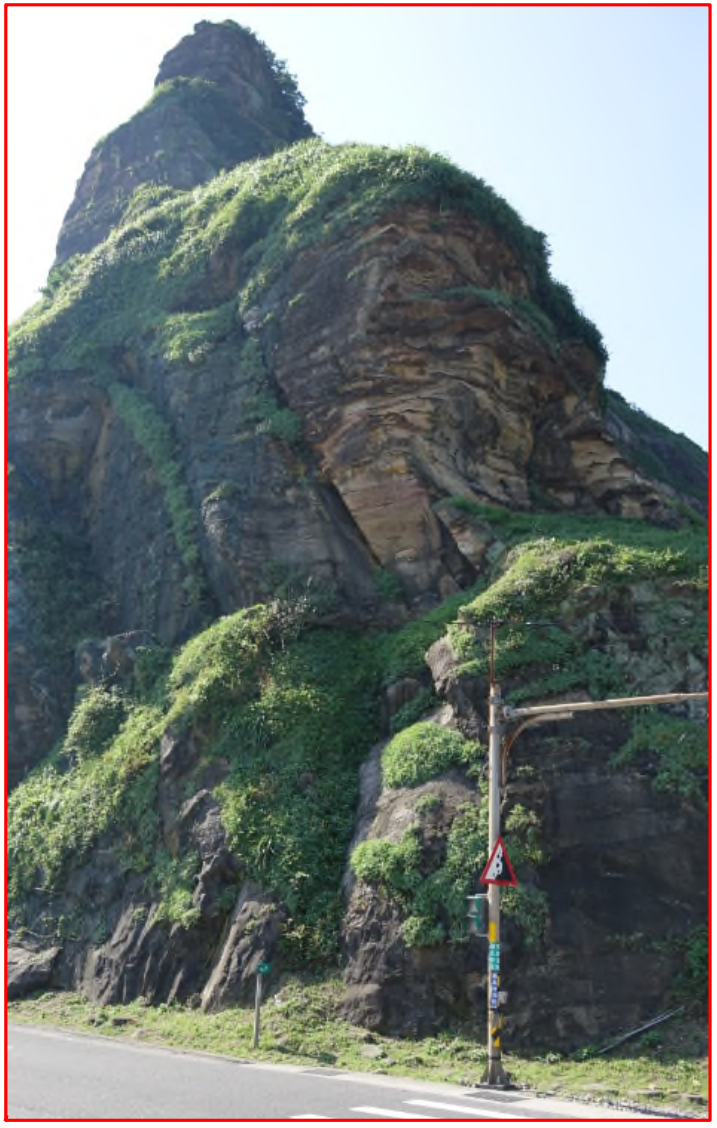
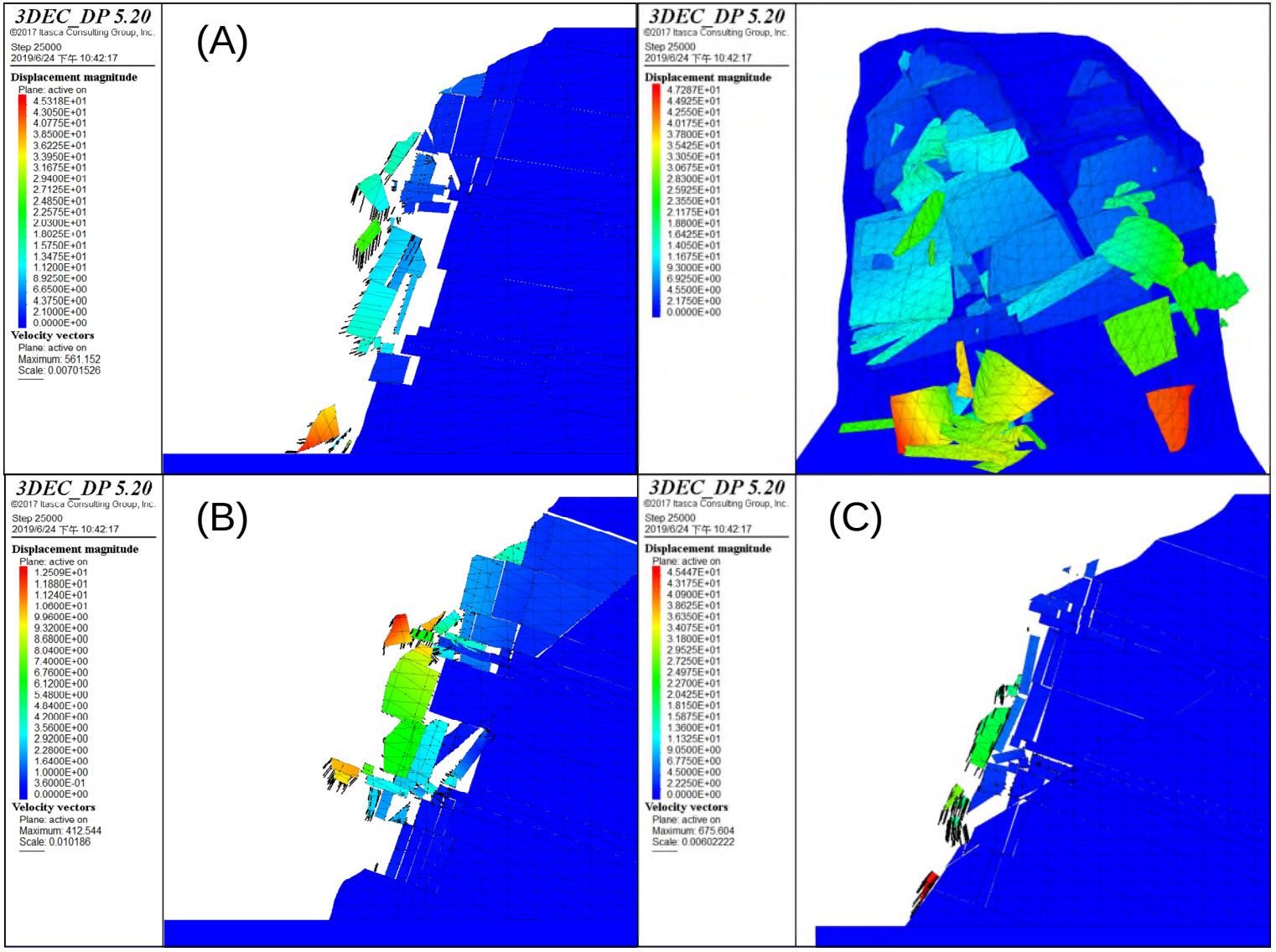
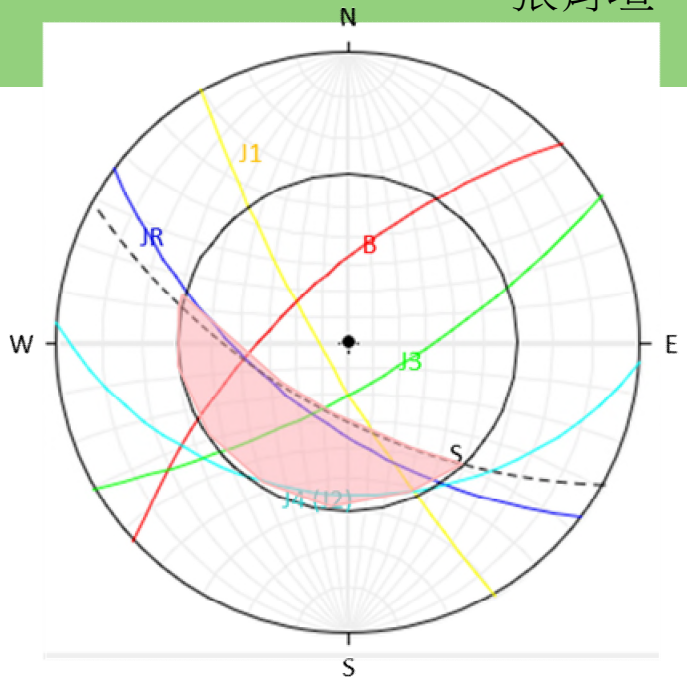


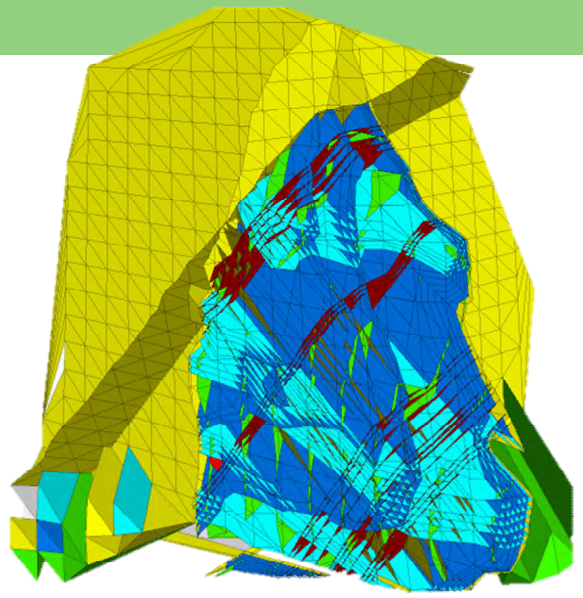
研究成果:現地數值模擬 — 主要節理延續性80%



北橫32.5K案例節理幾何特性

張育瑄、黃韋凱、林劭儒、林銘郎、翁孟嘉、林承翰





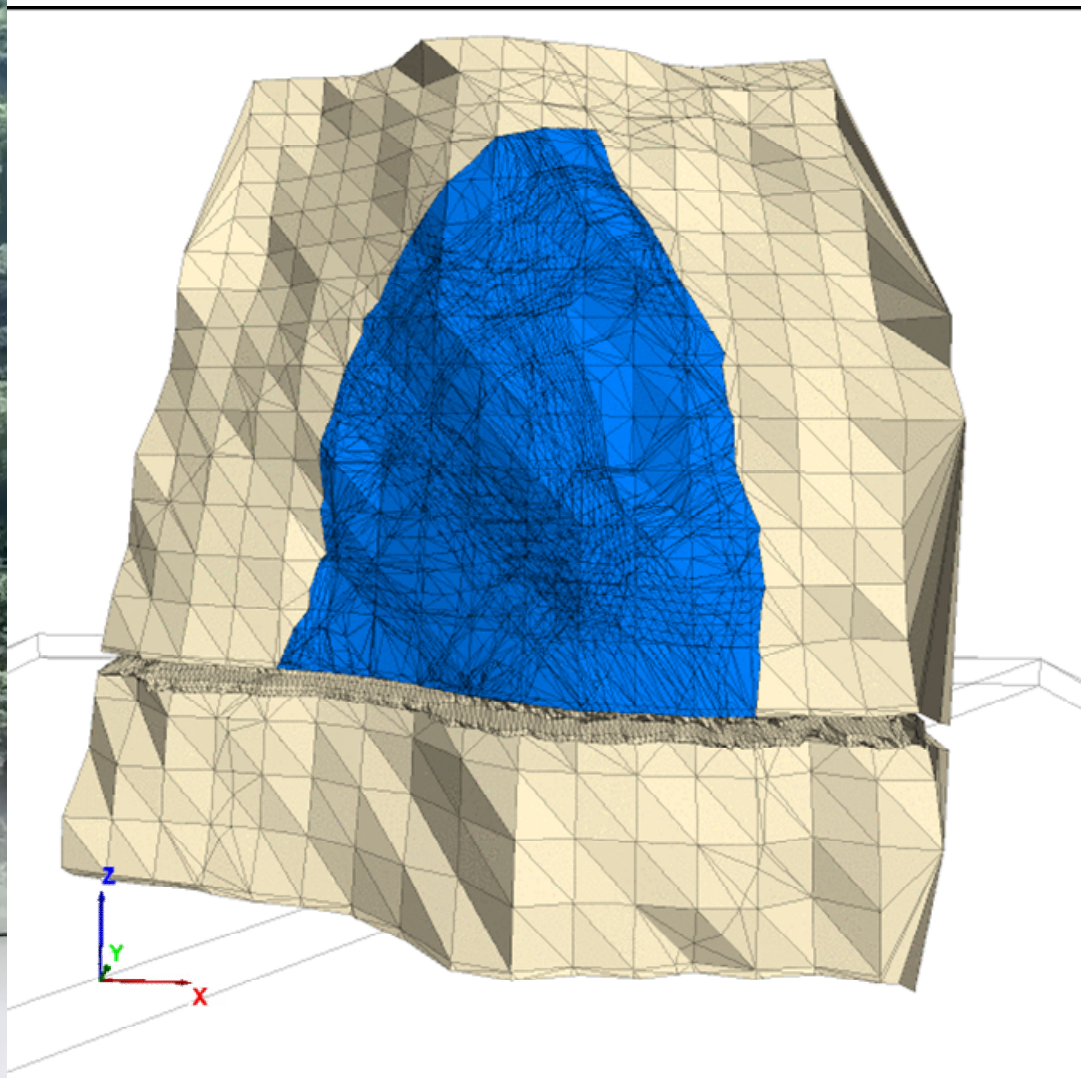
ID	Dip/Dip Dir.	Name	spacing	p
1	65/317	B	1.24	0.5
2	60/217	JR	0.76	0.9
3	72/150	J3	9.43	0.5
4	80/60	J1	1.34	0.2
5	63/209	S		
6	35/184 (35/206)	J2 (J4)	0.96	0.9

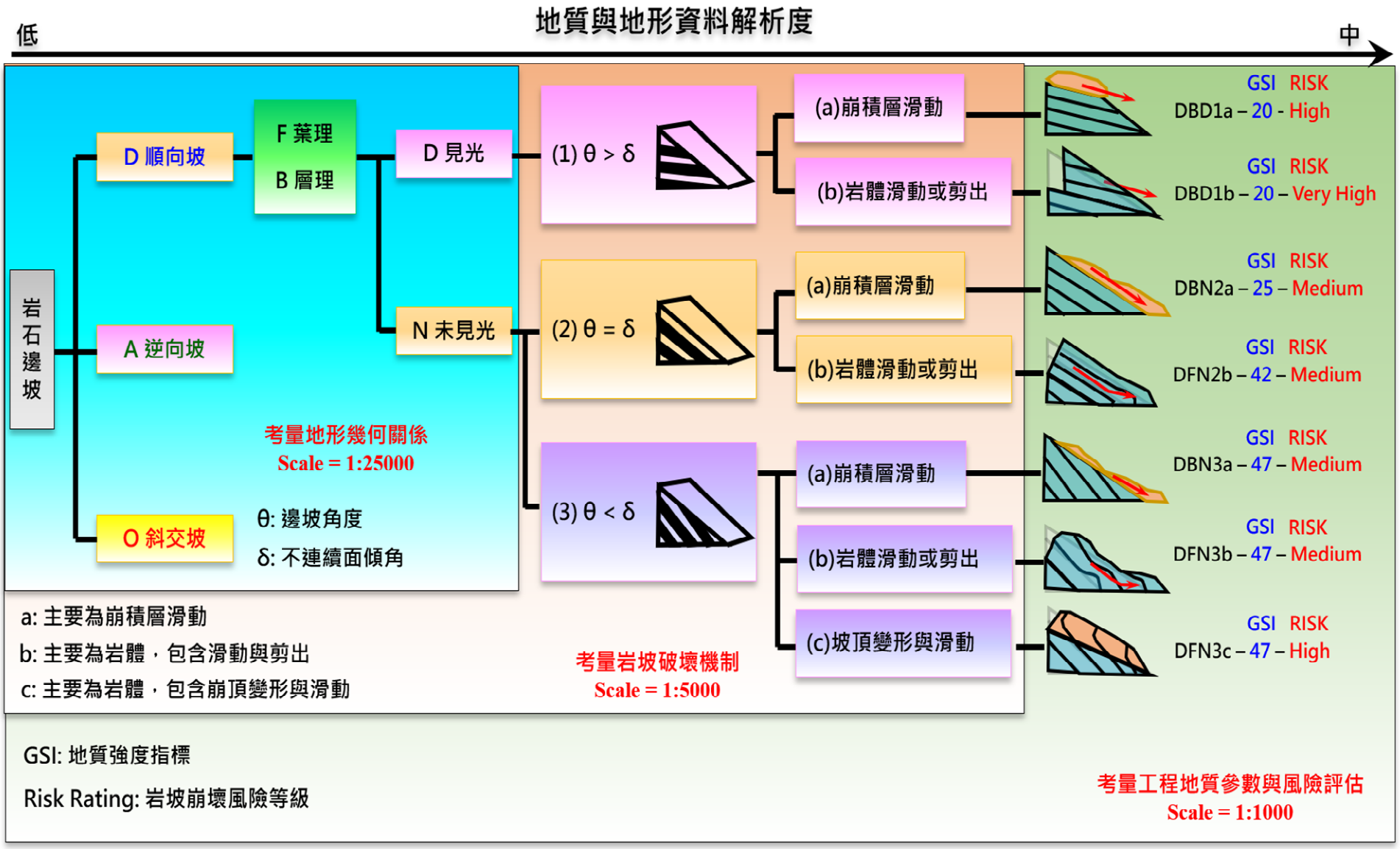
北橫32.5K案例崩塌情形

張育瑄、黃韋凱、林劭儒、林銘郎、翁孟嘉、林承翰

左下→左上→右上→右下(小規模落石)






地質與地形資料解析度
低
中
岩石邊坡
D 順向坡
F 葉理
B 層理
D 見光
N 未見光
A 逆向坡
O 斜交坡
考量地形幾何關係
Scale = 1:25000
θ: 邊坡角度
δ: 不連續面傾角
(1) θ > δ
(2) θ = δ
(3) θ < δ
(a)崩積層滑動
(b)岩體滑動或剪出
(a)崩積層滑動
(b)岩體滑動或剪出
(a)崩積層滑動
(b)岩體滑動或剪出
(c)坡頂變形與滑動
GSI RISK
DBD1a – 20 - High
GSI RISK
DBD1b – 20 – Very High
GSI RISK
DBN2a – 25 – Medium
GSI RISK
DFN2b – 42 – Medium
GSI RISK
DBN3a – 47 – Medium
GSI RISK
DFN3b – 47 – Medium
GSI RISK
DFN3c – 47 – High
a: 主要為崩積層滑動
b: 主要為岩體，包含滑動與剪出
c: 主要為岩體，包含崩頂變形與滑動
考量岩坡破壞機制
Scale = 1:5000
GSI: 地質強度指標
Risk Rating: 岩坡崩壞風險等級
考量工程地質參數與風險評估
Scale = 1:1000

地質與地形資料解析度

中 → 高

考量岩坡破壞機制
Scale = 1:5000

(1) θ > δ
- (a)崩積層滑動
- (b)岩體滑動或剪出

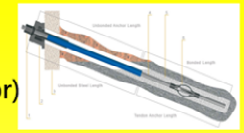
(2) θ = δ
- (a)崩積層滑動
- (b)岩體滑動或剪出

(3) θ < δ
- (a)崩積層滑動
- (b)岩體滑動或剪出
- (c)坡頂變形與滑動

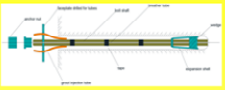
考量工程地質參數與風險評估
Scale = 1:1000

	GSI	RISK	
DBD1a	20	High	(e) + (f)
DBD1b	20	Very High	(a) + (d) + (e) + (g) (加入排水相關工法)
DBN2a	25	Medium	(c) + (e) + (f)
DFN2b	42	Medium	(a) + (d) + (g) (加入排水相關工法)
DBN3a	47	Medium	(d) + (f)
DFN3b	47	Medium	(b) + (d) + (e) + (g) (加入排水相關工法)
DFN3c	47	High	(b) + (d) + (e) + (g) (加入排水相關工法)

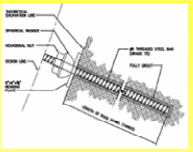
(a) 岩錨 (Rock Anchor)



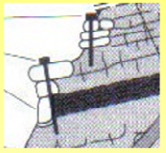
(b) 岩栓 (Rock Bolt)



(c) 岩釘 (Rock Dowel)



(d) 補隙 (Dentition)



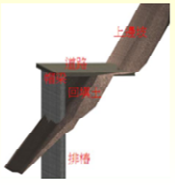
(e) 扶牆 (Buttress)



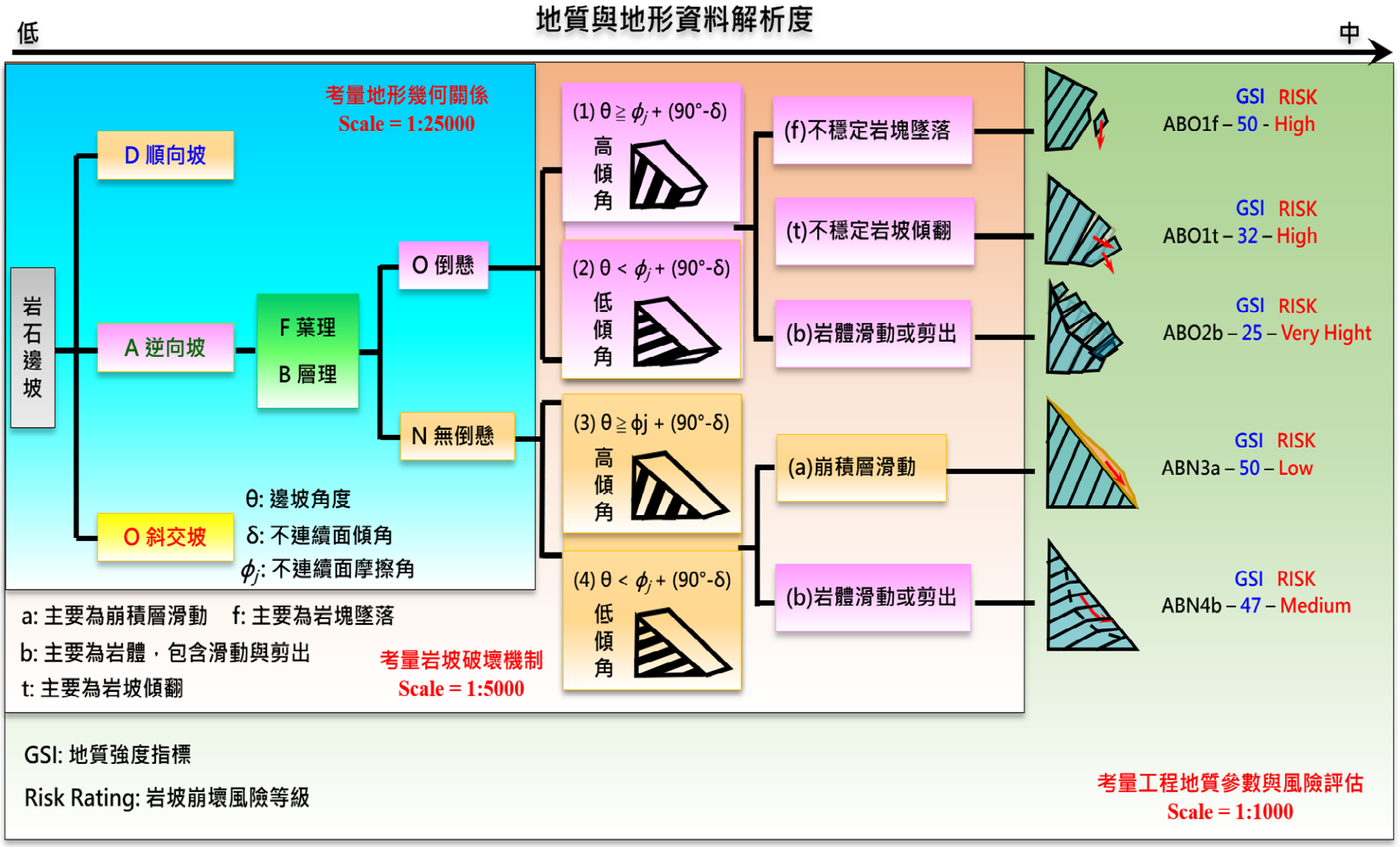
(f) 噴漿處理 (Gunite facing)



(g) 排樁工法 (Boring piles method)



考量岩坡治理工法
Scale > 1:500


地質與地形資料解析度
低
中
考量地形幾何關係
Scale = 1:25000
D 順向坡
A 逆向坡
O 斜交坡
岩石邊坡
F 葉理
B 層理
O 倒懸
N 無倒懸
θ: 邊坡角度
δ: 不連續面傾角
ϕ_j: 不連續面摩擦角
(1) θ ≧ ϕ_j + (90°-δ)
高傾角
(2) θ < ϕ_j + (90°-δ)
低傾角
(3) θ ≧ ϕj + (90°-δ)
高傾角
(4) θ < ϕ_j + (90°-δ)
低傾角
(f)不穩定岩塊墜落
(t)不穩定岩坡傾翻
(b)岩體滑動或剪出
(a)崩積層滑動
(b)岩體滑動或剪出
GSI RISK
ABO1f – 50 - High
GSI RISK
ABO1t – 32 – High
GSI RISK
ABO2b – 25 – Very Hight
GSI RISK
ABN3a – 50 – Low
GSI RISK
ABN4b – 47 – Medium
a: 主要為崩積層滑動 f: 主要為岩塊墜落
b: 主要為岩體，包含滑動與剪出
t: 主要為岩坡傾翻
考量岩坡破壞機制
Scale = 1:5000
GSI: 地質強度指標
Risk Rating: 岩坡崩壞風險等級
考量工程地質參數與風險評估
Scale = 1:1000

地質與地形資料解析度

中 → 高

(1) $\theta \geq \phi_j + (90°-\delta)$ 高傾角

(2) $\theta < \phi_j + (90°-\delta)$ 低傾角

(3) $\theta \geq \phi j + (90°-\delta)$ 高傾角

(4) $\theta < \phi_j + (90°-\delta)$ 低傾角

(f)不穩定岩塊墜落

(t)不穩定岩坡傾翻

(b)岩體滑動或剪出

(a)崩積層滑動

(b)岩體滑動或剪出

考量岩坡破壞機制
Scale = 1:5000

GSI RISK
ABO1f – 50 - High → (b) + (f) + (g)

GSI RISK
ABO1t – 32 – High → (a) + (b) + (e)

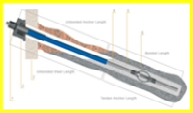
GSI RISK
ABO2b – 25 – Very Hight → (a) + (e) + (h)
(加入排水相關工法)

GSI RISK
ABN3a – 50 – Low → (e) + (g)

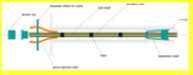
GSI RISK
ABN4b – 47 – Medium → (b) + (c) + (e) + (h)
(加入排水相關工法)

考量工程地質參數與風險評估
Scale = 1:1000

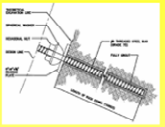
(a) 岩錨 (Rock Anchor)



(b) 岩栓 (Rock Bolt)



(c) 岩釘 (Rock Dowel)



(d) 補隙 (Dentition)



(e) 扶牆 (Buttress)



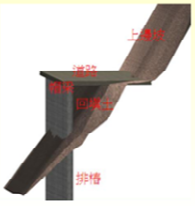
(f) 噴漿處理 (Gunite facing)



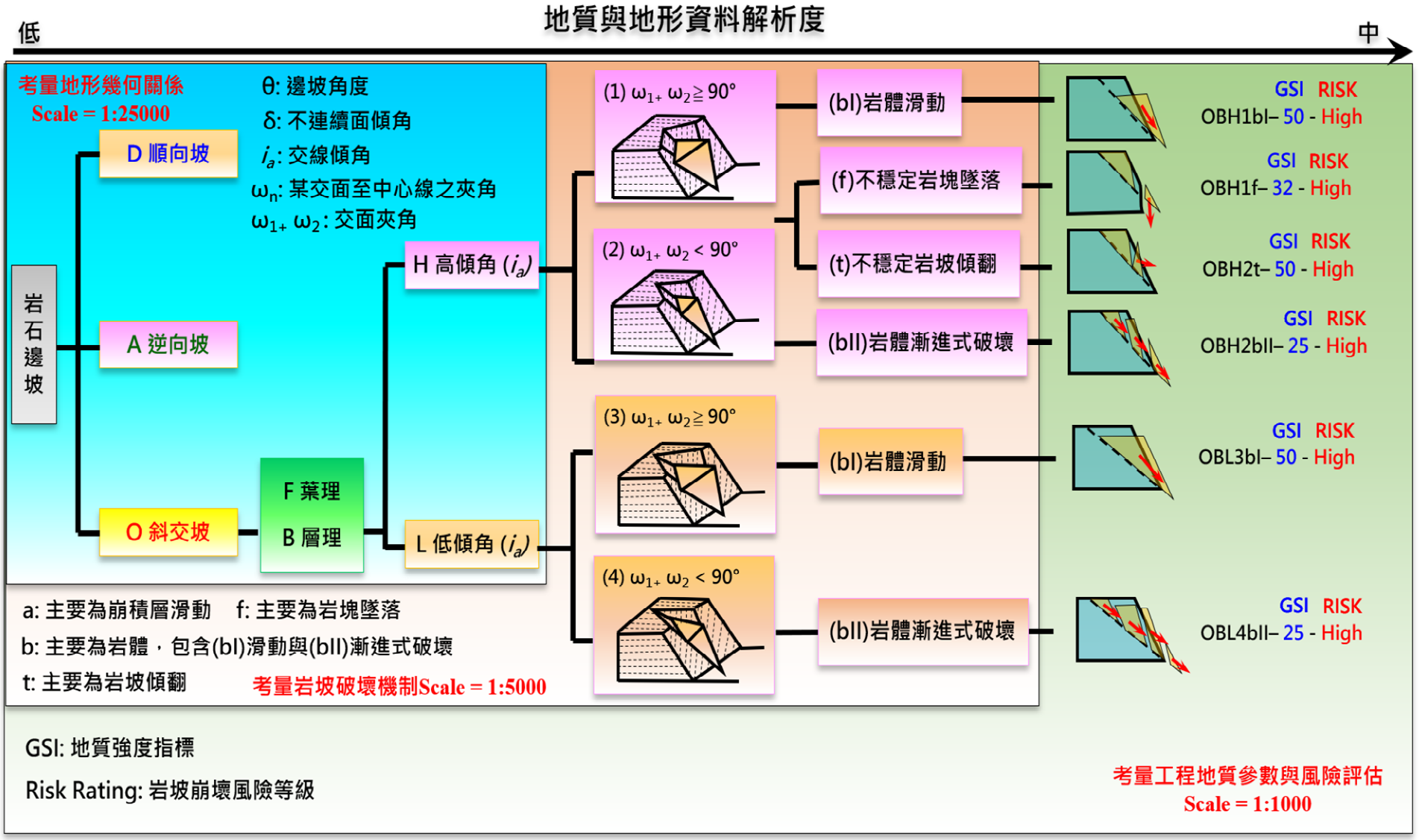
(g) 落石網 (Rockfall Netting)



(h) 排樁工法 (Boring piles method)



考量岩坡治理工法
Scale > 1:500


地質與地形資料解析度
低
中
考量地形幾何關係
Scale = 1:25000
θ: 邊坡角度
δ: 不連續面傾角
i_a: 交線傾角
ω_n: 某交面至中心線之夾角
ω_{1+} ω_2: 交面夾角
岩石邊坡
D 順向坡
A 逆向坡
O 斜交坡
F 葉理
B 層理
H 高傾角 (i_a)
L 低傾角 (i_a)
(1) ω_{1+} $\omega_2 \geqq 90°$
(2) ω_{1+} $\omega_2 < 90°$
(3) ω_{1+} $\omega_2 \geqq 90°$
(4) ω_{1+} $\omega_2 < 90°$
(bI)岩體滑動
(f)不穩定岩塊墜落
(t)不穩定岩坡傾翻
(bII)岩體漸進式破壞
(bI)岩體滑動
(bII)岩體漸進式破壞
GSI RISK
OBH1bI– 50 - High
GSI RISK
OBH1f– 32 - High
GSI RISK
OBH2t– 50 - High
GSI RISK
OBH2bII– 25 - High
GSI RISK
OBL3bI– 50 - High
GSI RISK
OBL4bII– 25 - High
a: 主要為崩積層滑動 f: 主要為岩塊墜落
b: 主要為岩體，包含(bI)滑動與(bII)漸進式破壞
t: 主要為岩坡傾翻
考量岩坡破壞機制Scale = 1:5000
GSI: 地質強度指標
Risk Rating: 岩坡崩壞風險等級
考量工程地質參數與風險評估
Scale = 1:1000

地質與地形資料解析度

中 → 高

(1) ω_{1+} $\omega_2 \geq 90°$ — (bI)岩體滑動 — GSI RISK OBH1bI– 50 - High → (a) + (b) + (c) + (e) + (h)

(2) ω_{1+} $\omega_2 < 90°$ — (f)不穩定岩塊墜落 — GSI RISK OBH1f– 32 - High → (b) + (f) + (g)

(2) ω_{1+} $\omega_2 < 90°$ — (t)不穩定岩坡傾翻 — GSI RISK OBH2t– 50 - High → (a) + (b) + (e)

(2) ω_{1+} $\omega_2 < 90°$ — (bII)岩體漸進式破壞 — GSI RISK OBH2bII– 25 - High → (b) + (c) + (e) + (f) + (h) (加入排水相關工法)

(3) ω_{1+} $\omega_2 \geq 90°$ — (bI)岩體滑動 — GSI RISK OBL3bI– 50 - High → (a) + (b) + (c) + (e) + (h)

(4) ω_{1+} $\omega_2 < 90°$ — (bII)岩體漸進式破壞 — GSI RISK OBL4bII– 25 - High → (b) + (c) + (e) + (f) + (h) (加入排水相關工法)

考量工程地質參數與風險評估
Scale = 1:1000

(a) 岩錨 (Rock Anchor)

(b) 岩栓 (Rock Bolt)

(c) 岩釘 (Rock Dowel)

(d) 補隙 (Dentition)

(e) 扶牆 (Buttress)

(f) 噴漿處理 (Gunite facing)

(g) 落石網 (Rockfall Netting)

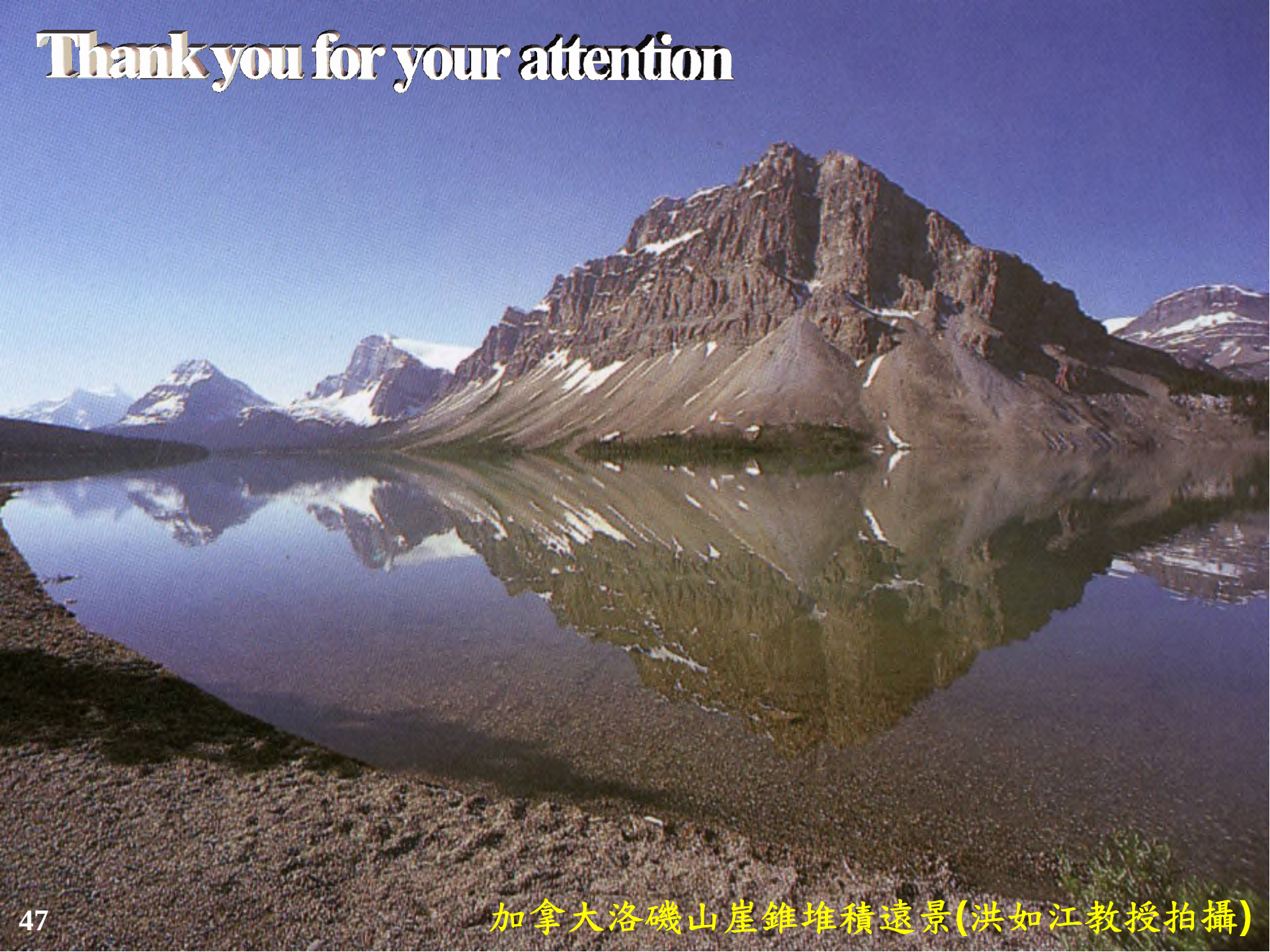
(h) 排樁工法 (Boring piles method)

考量岩坡治理工法
Scale > 1:500

林銘郎教授團隊結論

- 結合現代遙測技術、點雲技術、3D建模技術、力學分析等技術的快速發展，擬真的岩石邊坡變形乃至破壞的夢想，逐漸可以成真;尚缺真實監測資料比對、反算與驗証模式
- 岩體內部的節理特性，永遠是未知數。
- **促崩因子尚待更深入了解與研究**
- 多節理多階段複合型岩坡**變形狀態與破壞潛勢如何定義?**
- 革命尚未成功、**同學仍需努力**

Thank you for your attention



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