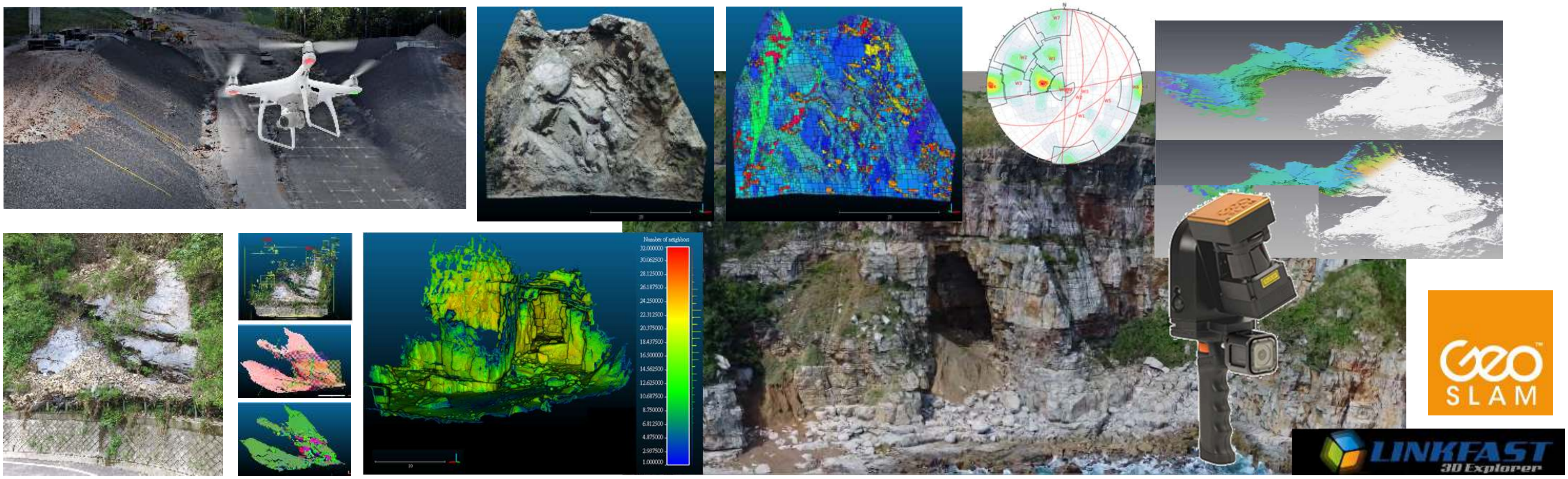


UAV攝影測量點雲分析應用於崩塌地表地質調查

報告人：財團法人中興工程顧問社 黃韋凱 副研究員

報告時間：2019/11/2

應用地質技師公會
財團法人中興工程顧問社
SINOTECH ENGINEERING CONSULTANTS, INC.

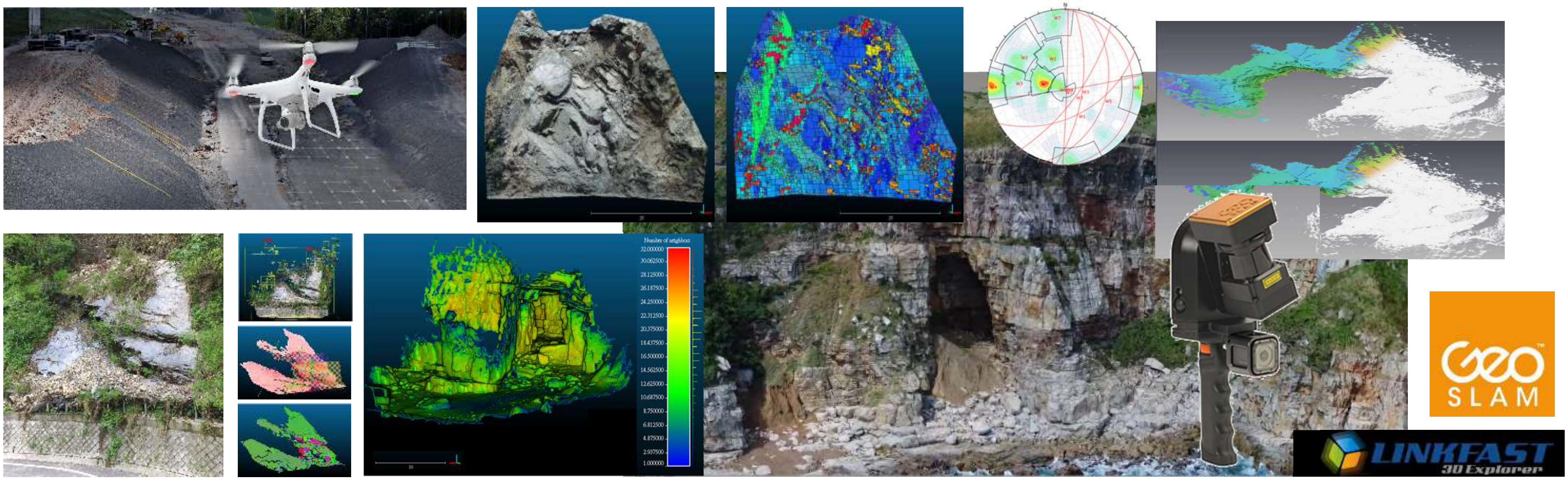
APPLIED Geolog1st 2019應用地質技術研討會

OUTLINE

1 山崩地表地質調查問題與解決方案

2 研究案例與初步成果

3 結論與討論

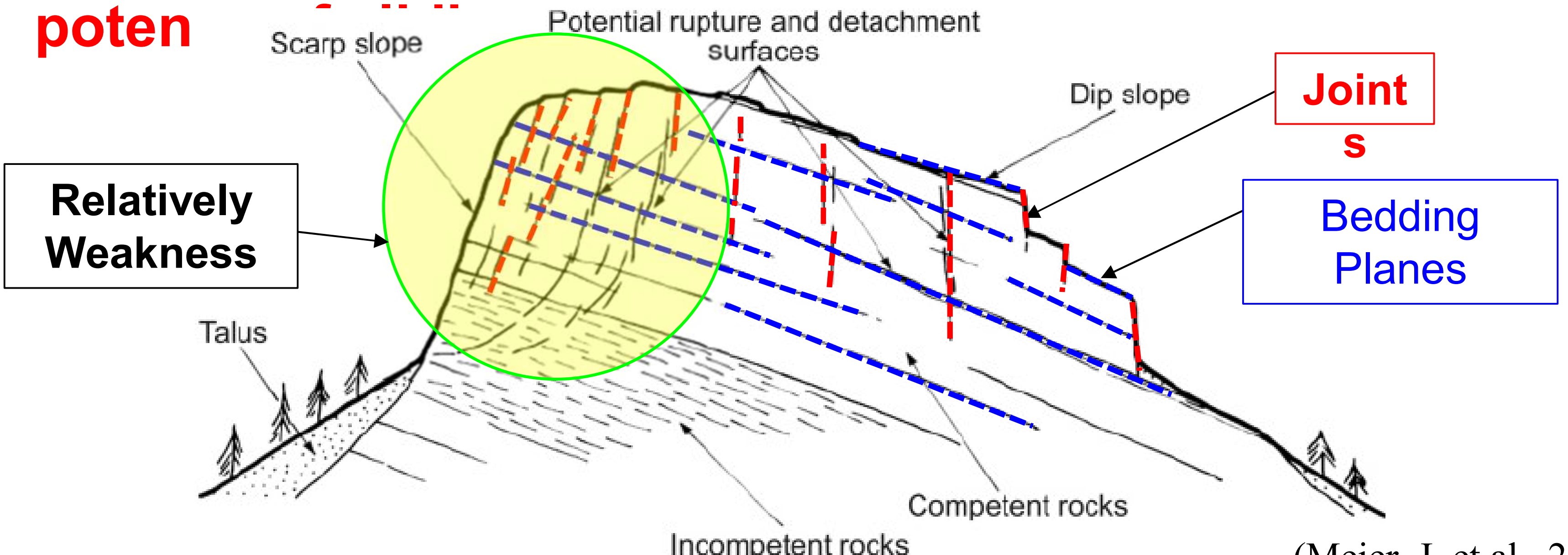


山崩地表地質調查問題與解決方案

UAV攝影測量點雲分析應用於崩塌地表地質調查

Role of Rock Discontinuities in Rock Slope Failure

- Discontinuities: **Joints**, Faults, **Bedding Planes**, Fractures, etc.
- Discontinuities reduce the rock mass strength
- Discontinuities control planes of weakness
- **Orientation** (Strike and dip) influence the **failure modes and poten**

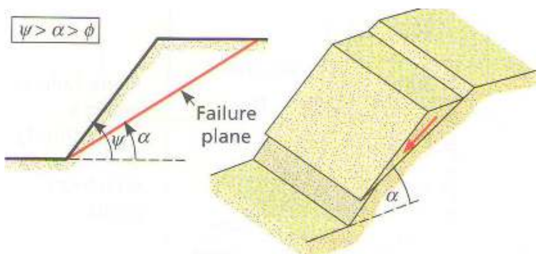


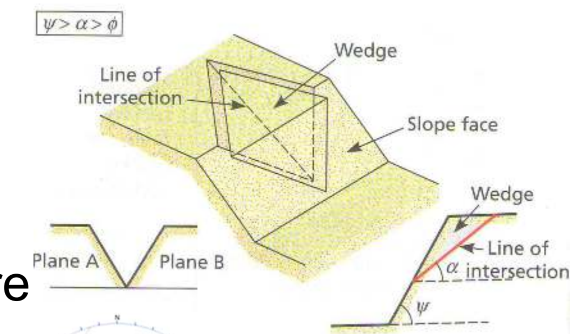
(Meier, J. et al., 2009)

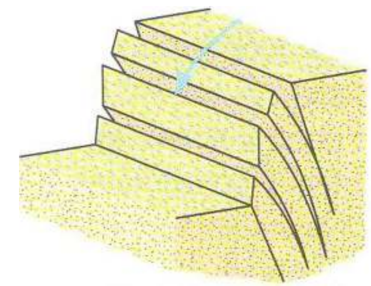
Basic mechanics of rock slope failure

Structurally controlled instability

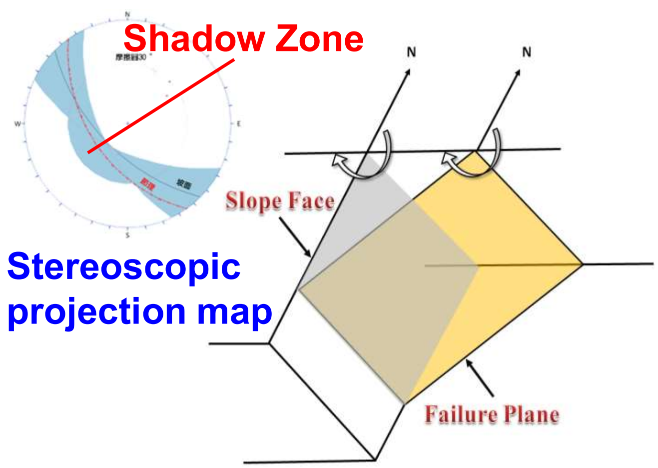
- Structurally-controlled instability means that **blocks** formed by discontinuities may be free to **slide** from a newly excavated slope face under a set of body forces (usually **gravity**). To assess the likelihood of such failures, an analysis of the **kinematic admissibility** of potential wedges or planes that intersect the excavation face(s) can be performed



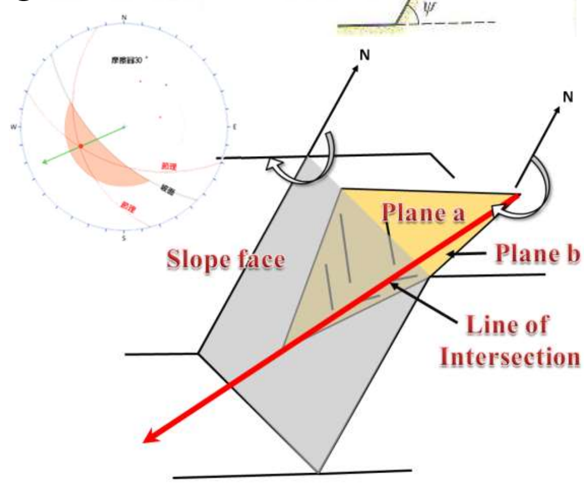




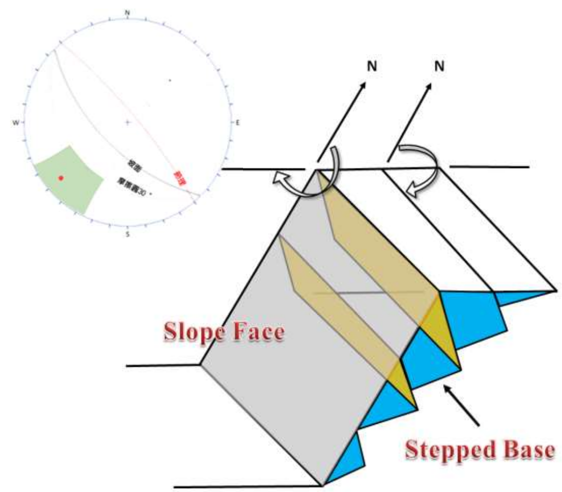
Typical type of rock slope failure



Planar failure



Wedge failure

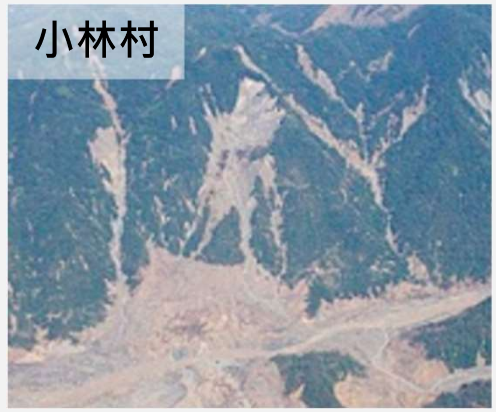


Toppling failure

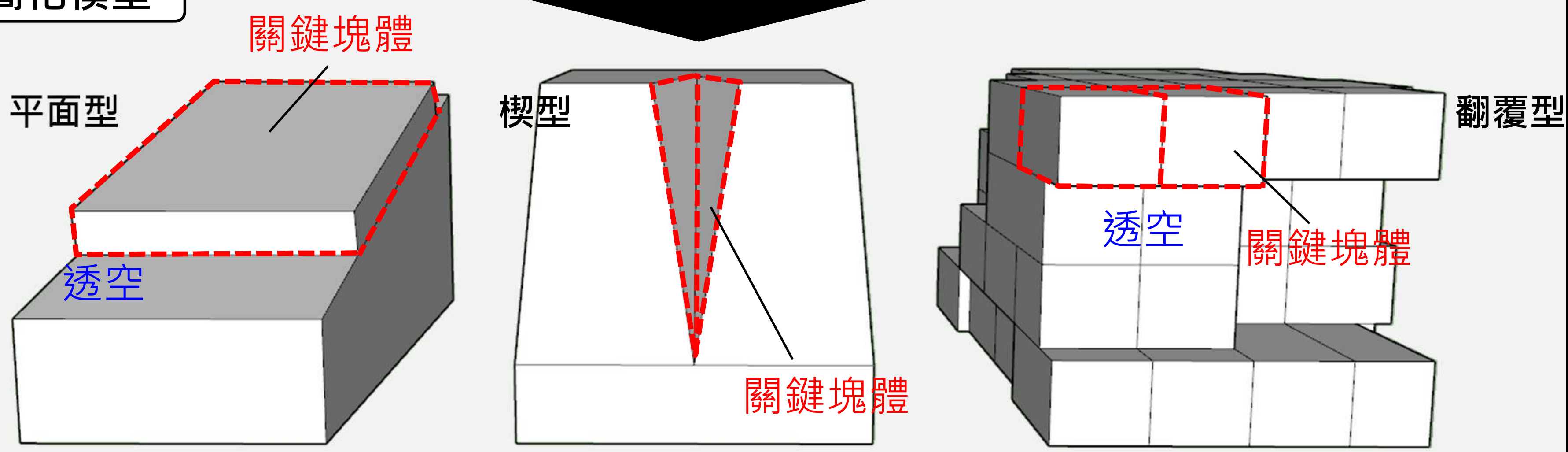
Hoek and Bray(1981)

災害機制與簡化模型

歷史災害狀況



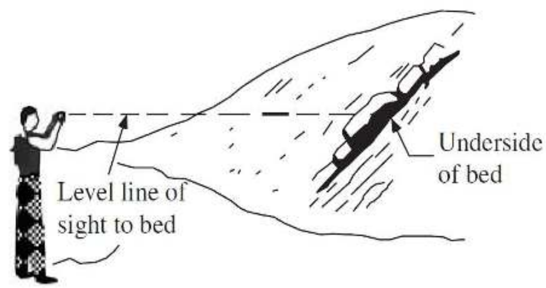
簡化模型

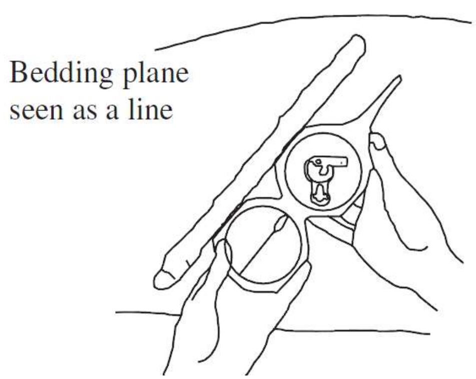


災害機制與簡化模型

潛勢區位無法擬定

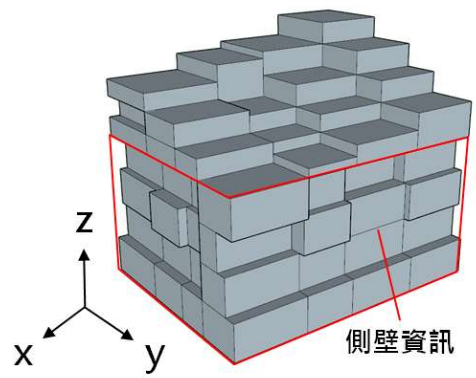
遠距遙測誤差



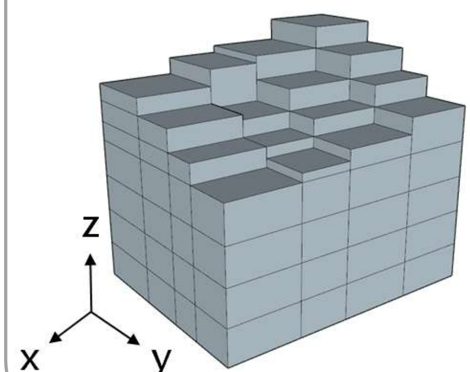


側壁資訊不足

簡化實際模型三維側視圖



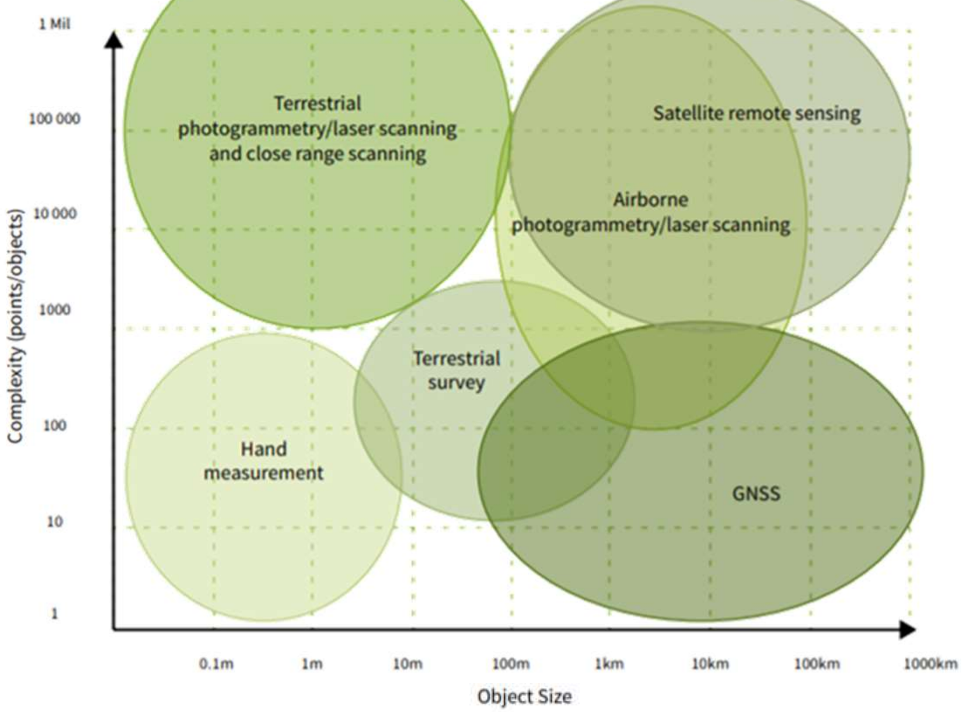
通用地理資訊系統三維展示圖

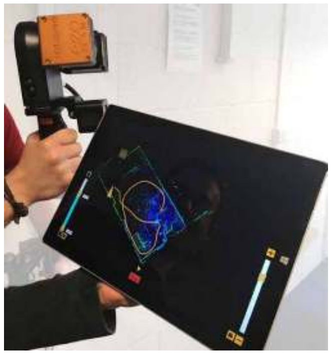


文獻回顧

遙測方法與掃描目標尺寸與解析度

(Boehler et. al., 2001)



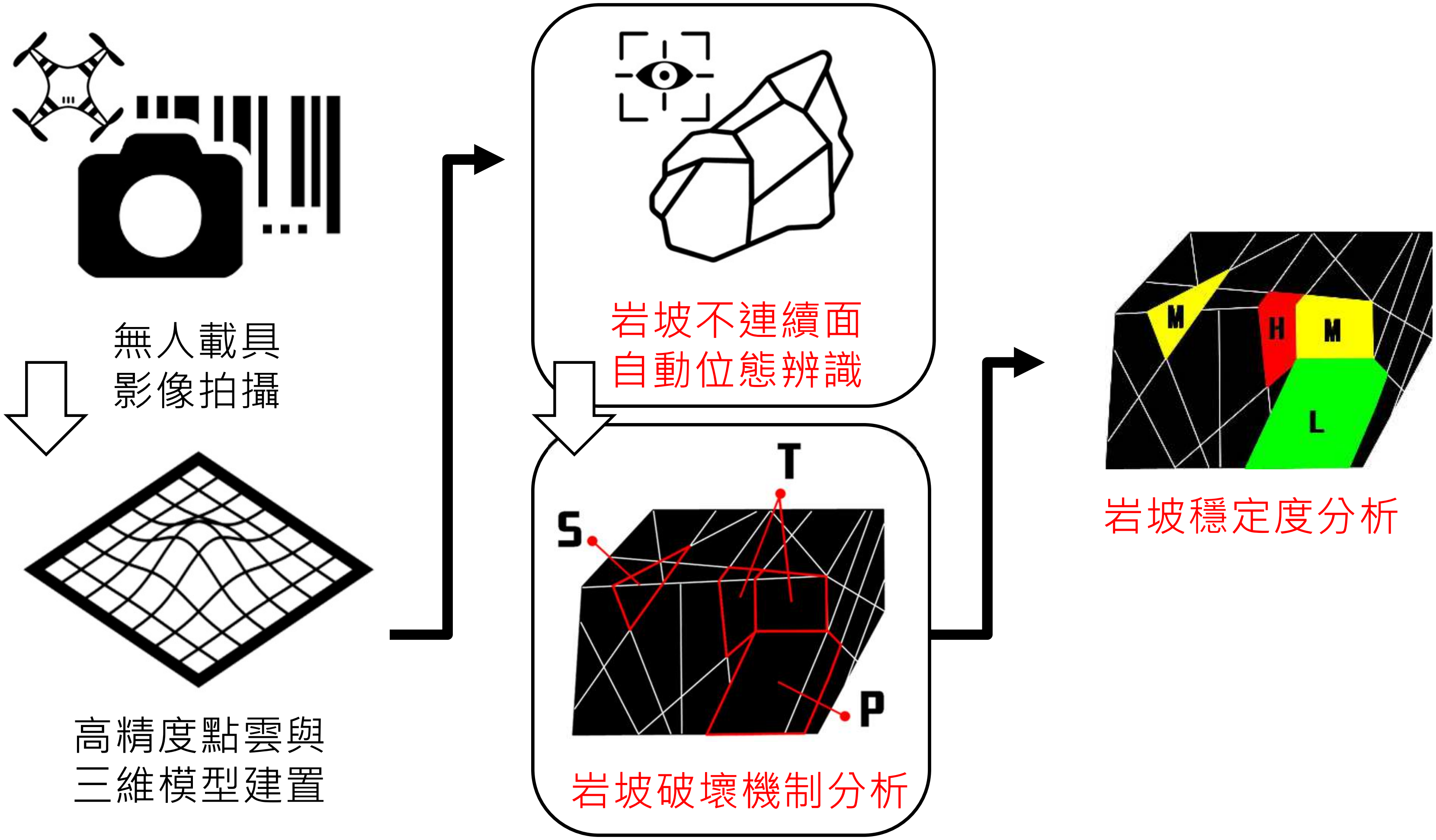


光達掃瞄系統與掃瞄用途及精度、測距說明表

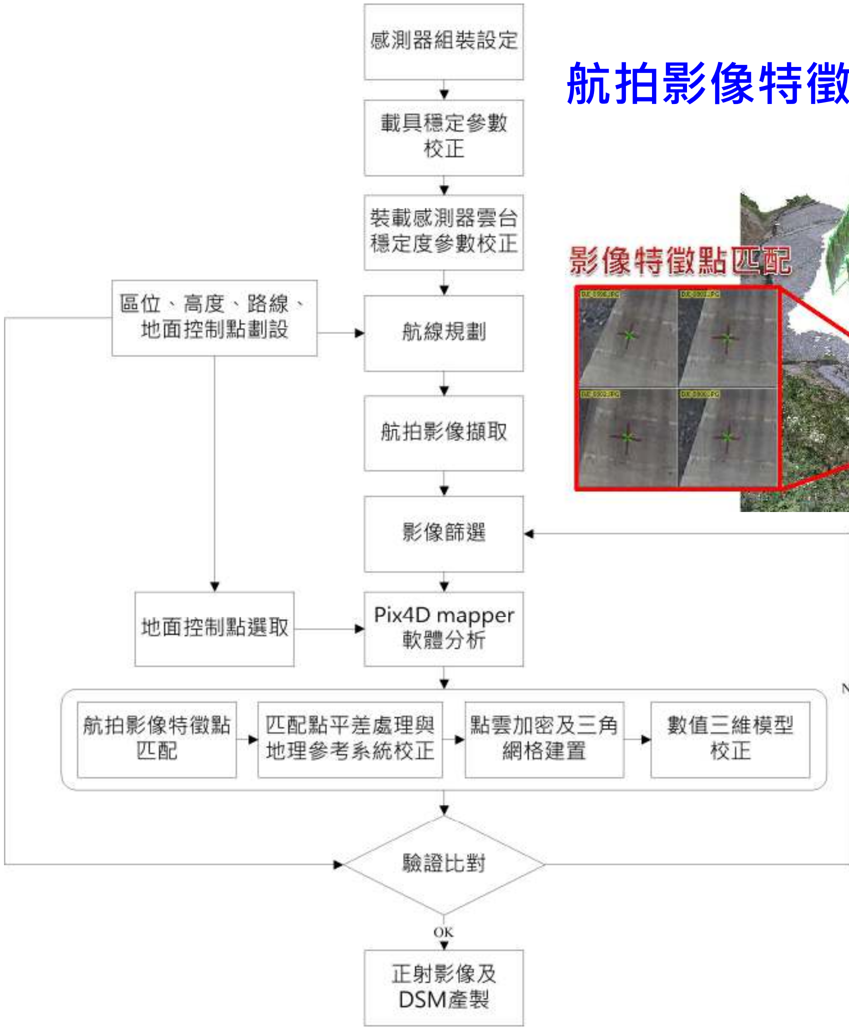
(Historic England, 2018)

測量方法/形式		模型建置對象	通用精度(mm)	通用測距(m)
三角測量法	旋轉台(rotation stage)	室內小型目標	0.05	0.1-1
	機械手臂(arm mounted)		0.05	0.1-3
	手持固定		0.03-1	0.2-0.3
	移動式(mobile mapping system)	地下結構(如:洞穴、隧道)、中型物件掃瞄	0.03-30	0.3-20
	三腳架式	小型物件掃瞄，室內外封閉式無延伸式中型目標	0.1-1	0.1-2.5
時差測距法	陸域	建築物內外結構	1-6	0.5-1000
	車載	街景、公路掃瞄	10-50	10-200
	無人飛行載具系統(UAS)	局部區域，處於廣闊地形下任何對象	20-200	10-125
	航空	廣域大範圍，處於廣闊地形下任何對象	50-300	100-3500
相位比較法	陸域	建築物內外結構	2-10	1-300

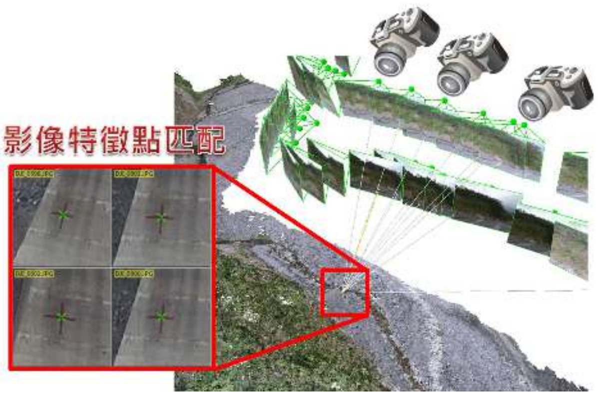
無人載具攝影測量與岩坡破壞機制分析流程



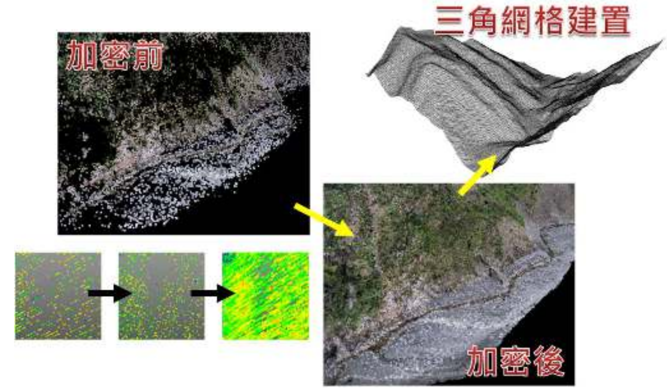
點雲、數值地表模型建置流程



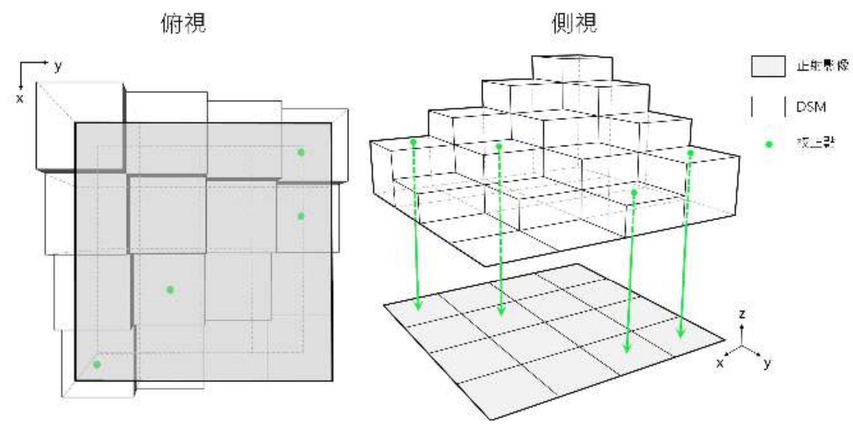
航拍影像特徵點匹配



點雲加密及三角網格建置



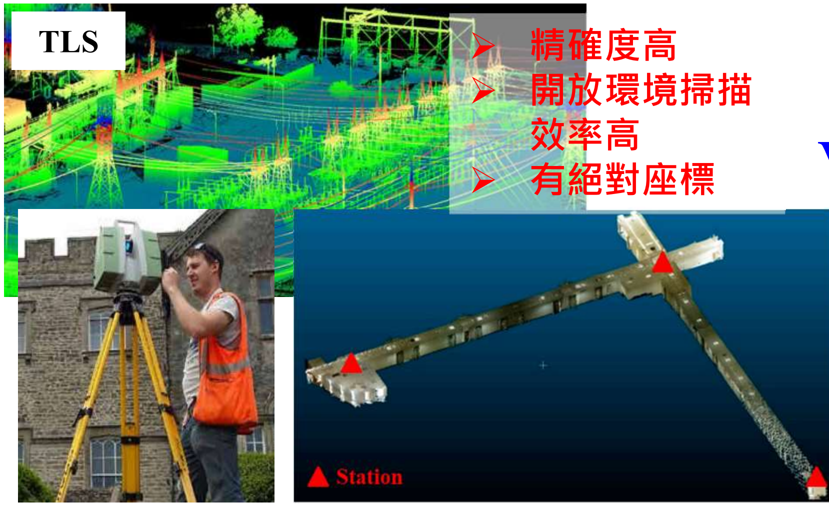
數值三維模型校正



※引用自黃韋凱(2017)等人

地面光達與手持式光達比較

Terrestrial vs Handheld Mobile Laser Scanning

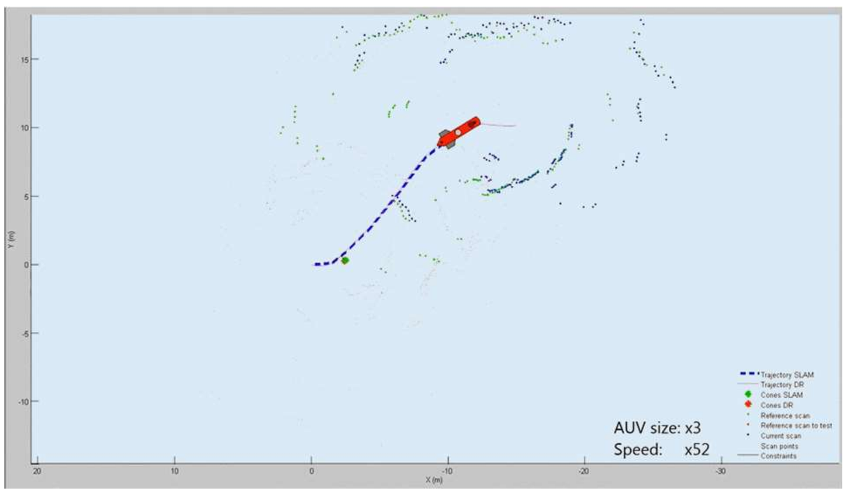


- 精確度高
- 開放環境掃描
- 效率高
- 有絕對座標

V.S.

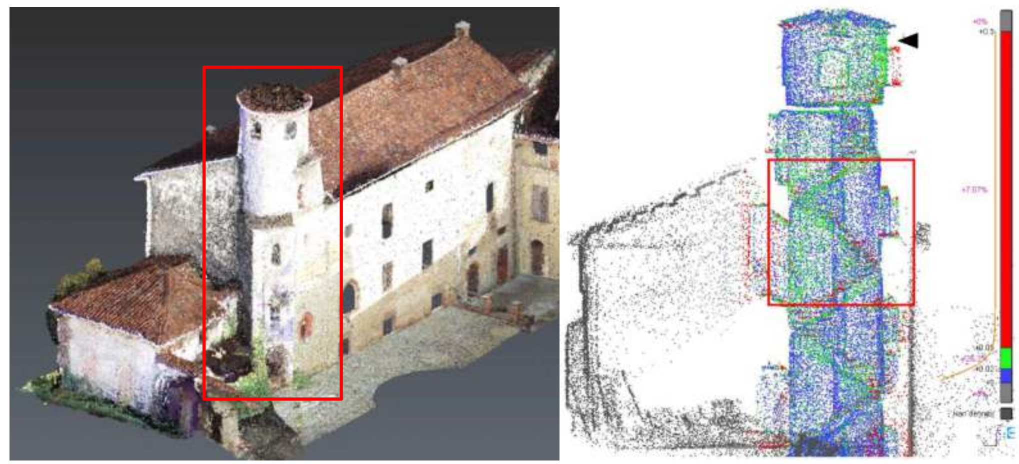
- 封閉、複雜
- 地形效率高
- 近距離細節豐富
- 無絕對座標

SLAM 即時視覺化運算以洞穴環境狀況為例



(Mallios A., et, al., 2015)

SLAM 即時視覺化運算以室內建築環境狀況為例



(Sammartano G., et al., 2018)

SLAM掃描技術

What is Geospatial SLAM?

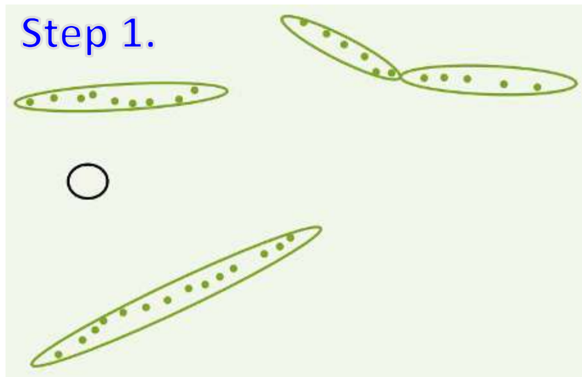
(Site from GeoSLAM Ltd)

Simultaneous

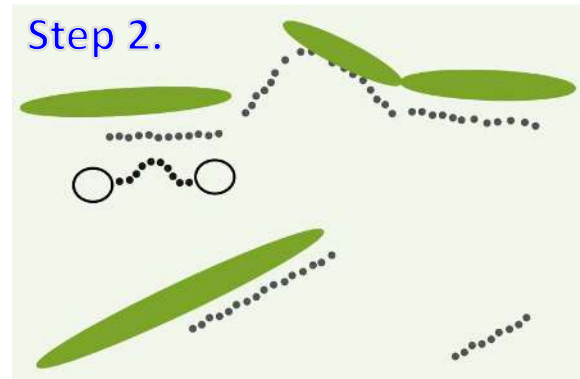
Localization

And

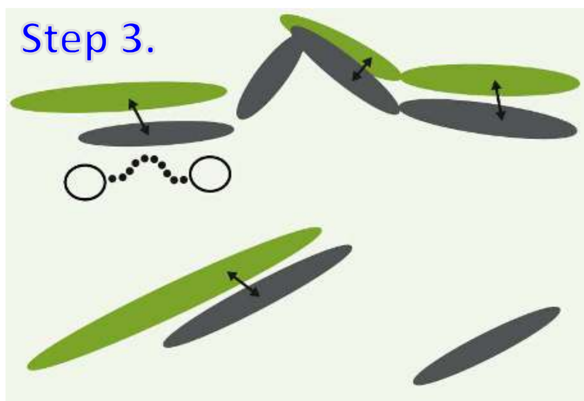
Mapping



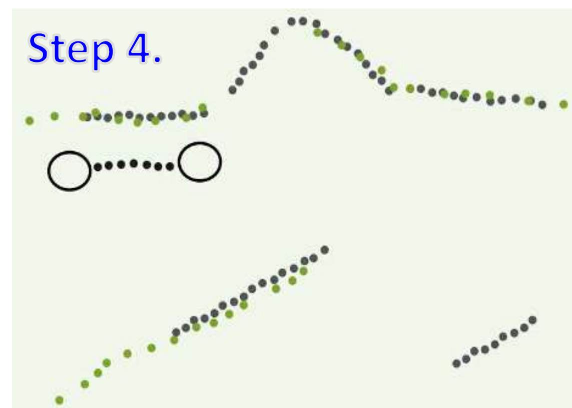
Create initial point cloud and extract 'Surfels(surface element)'



Calculate trajectory and point cloud for next sweep



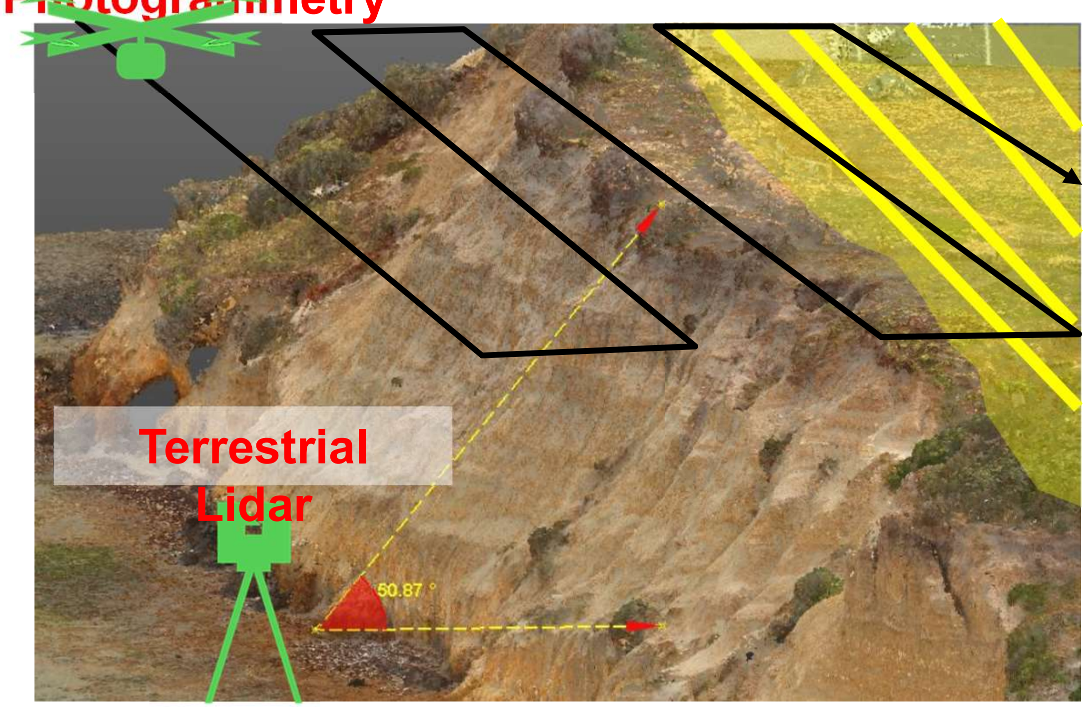
Extract and match 'Surfels' from both sweeps



Optimise trajectory and recreate point cloud

Advantage of UAV, and Multi-Data Analysis

UAV Photogrammetry



Airborne Lidar

Drone Route Planning

Terrestrial Lidar Scan Angle

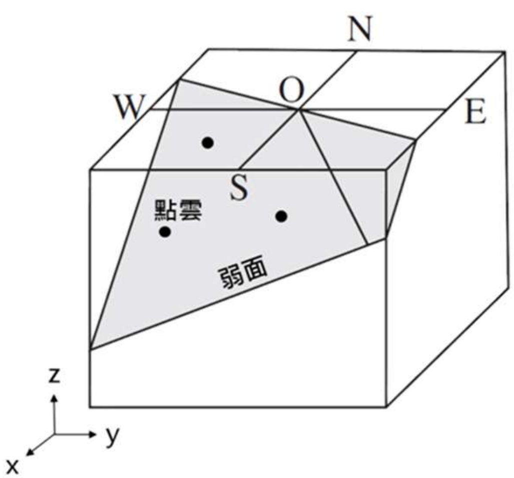
Unable to scan area

- The 3D models and point cloud data generated from photogrammetry is in full color, making them much more easier visualized and interpreted. You also get a 2D color map out of the same process.
- Cost down, and flexible allow the user to acquire dense point clouds from low-flying heights, or from favorable angles.

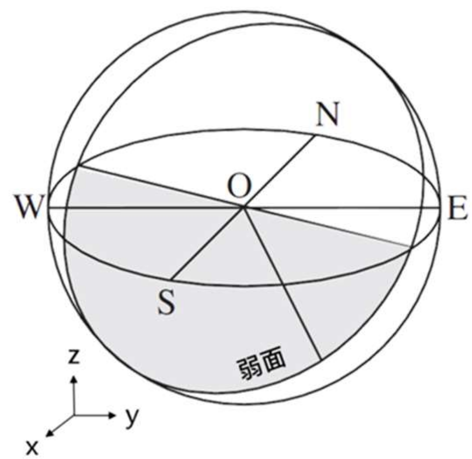
點雲資料與地質不連續面量測之轉換

野外露頭點雲構成不連續面情況與赤平投影圓轉換示意圖

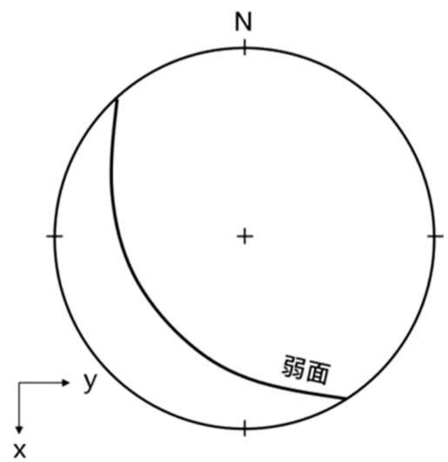
野外露頭狀況

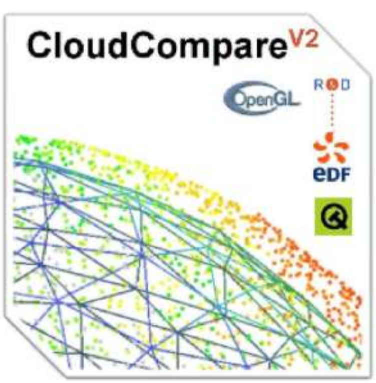


3維赤平投影圓

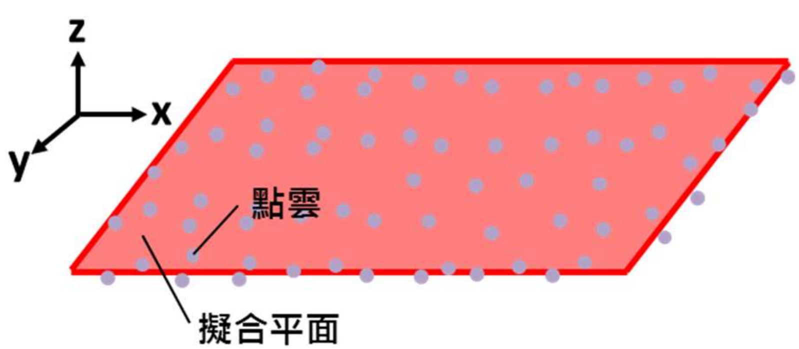


2維赤平圖影圓

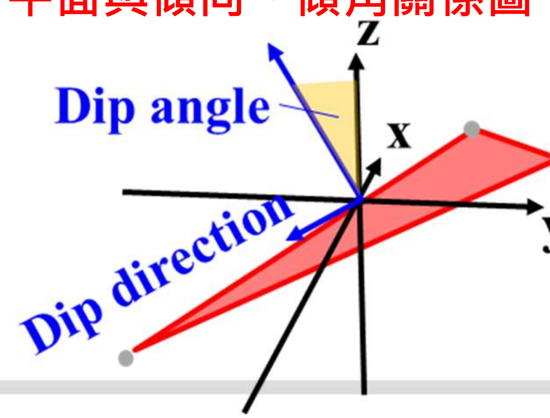


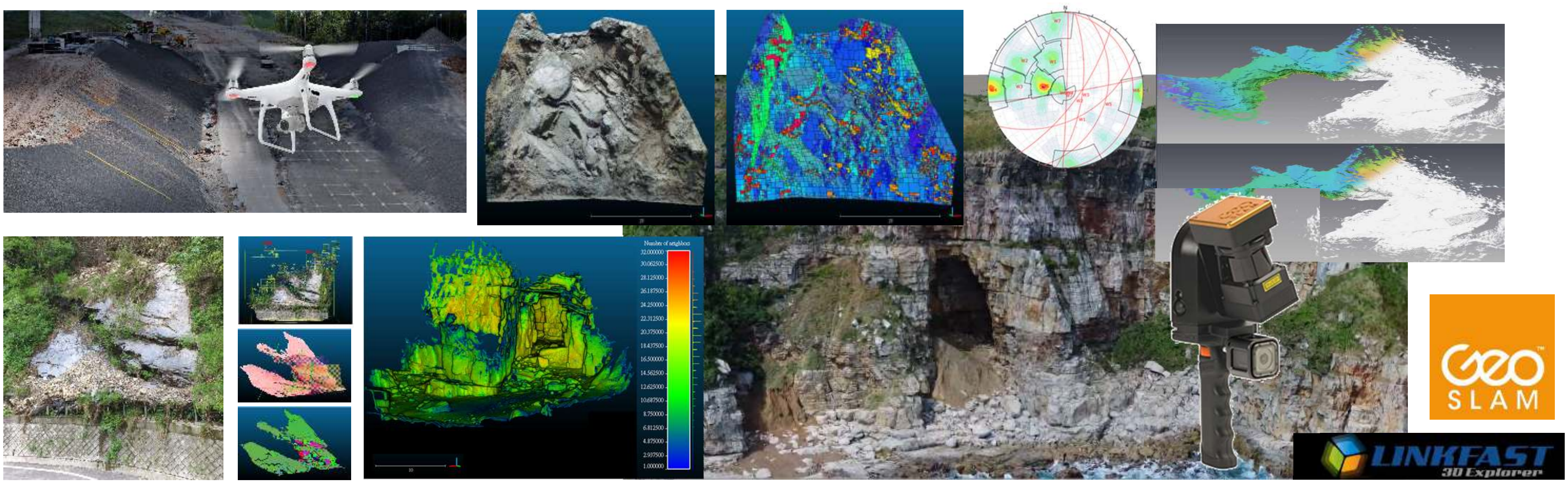


點雲擬合平面示意圖



擬合平面與傾向、傾角關係圖





研究案例與初步成果

UAV攝影測量點雲分析應用於崩塌地表地質調查

研究案例

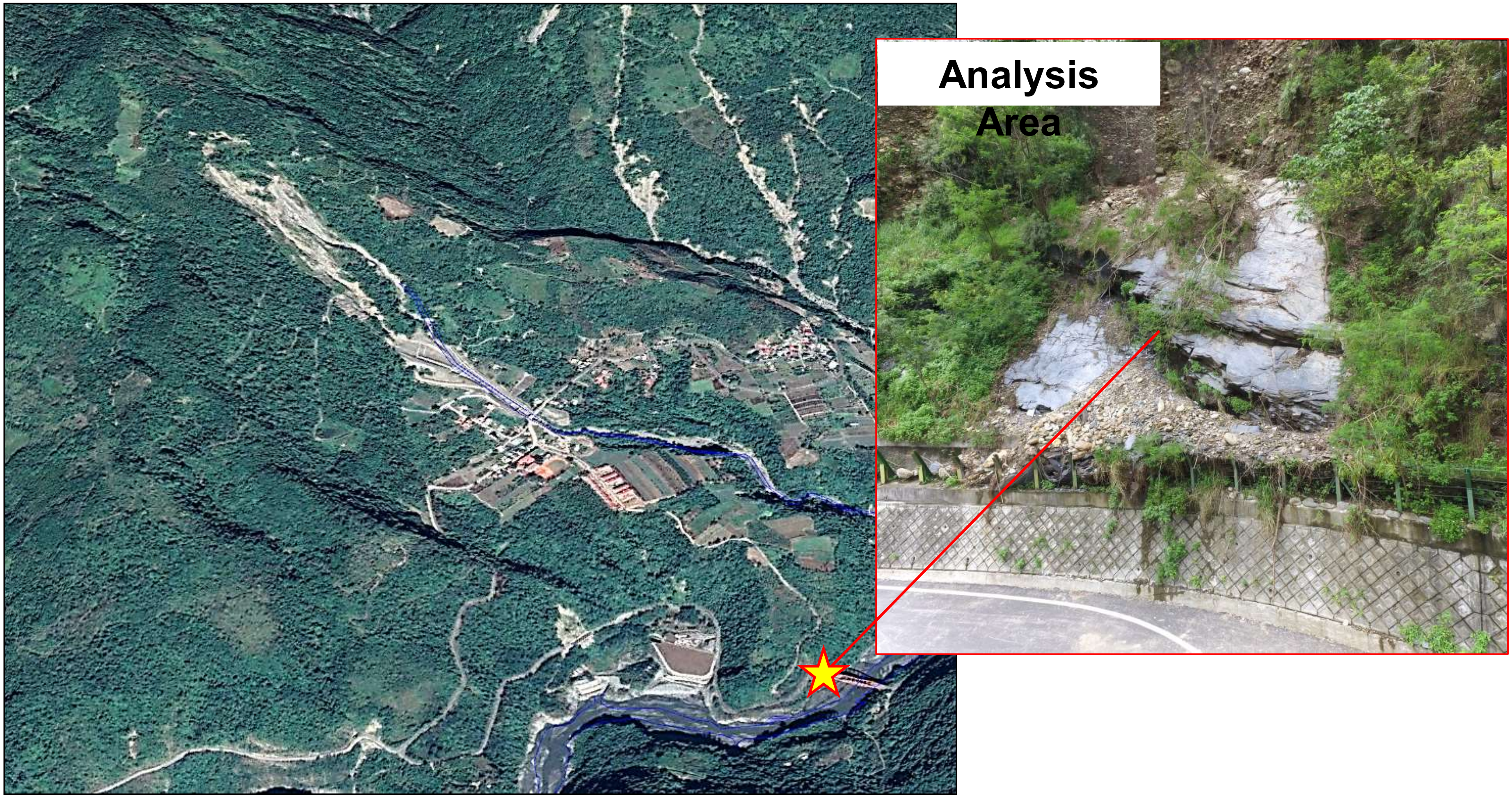
- **順向坡**
- 不連續面自動辨識
- 赤平投影圓與破壞機制分析
- 穩定分析

- **逆向坡**
- 手持式光達與UAV點雲比對分析
- 不連續面自動辨識

- **逆向坡**
- 節理破碎程度分析
- 岩石塊體形狀建置與落石路徑模擬

- **斜交坡**
- 不連續面自動辨識
- 赤平投影圓與破壞機制分析
- 倒懸危石辨識

The Disaster Event in Hung-Yeh

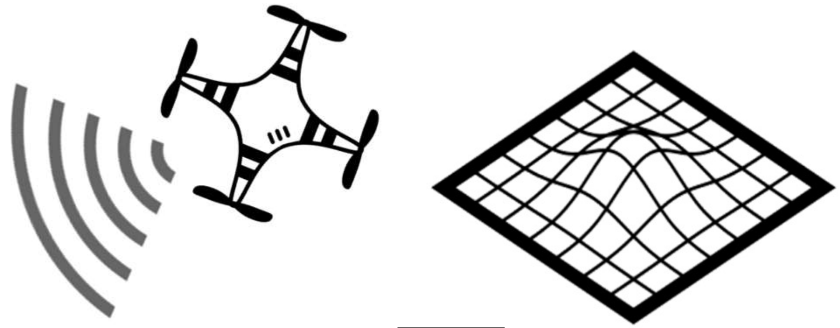


- In 14th Sep 2016, Typhoon Meranti brought more than 600mm rainfall in 2 days , in Hung-Yeh Village of Taitung County, more than 30 houses were destroyed by the debris flow. My analysis area is over here, and there shows a classic outcrop to know the geological situation underground.

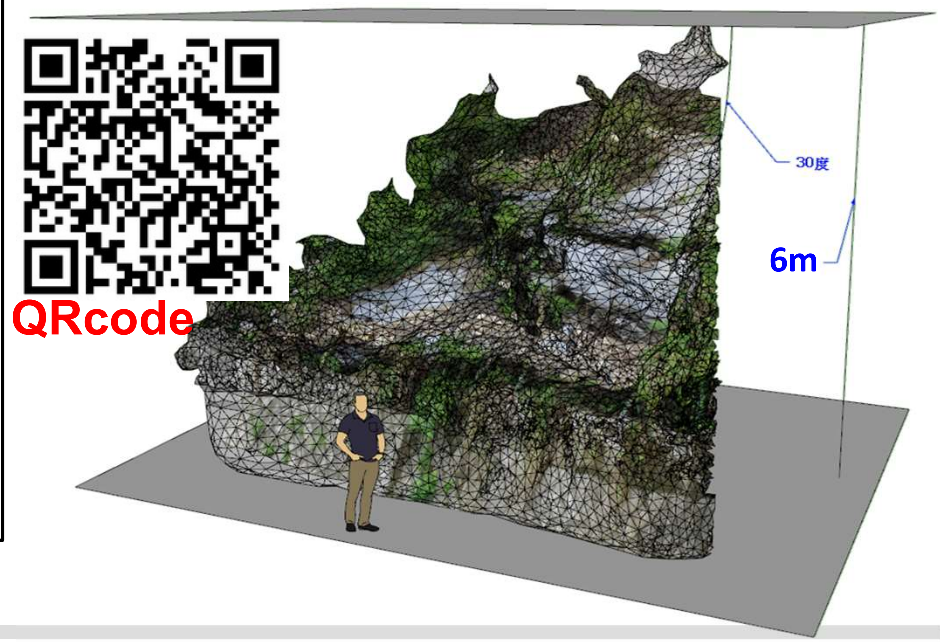
案例現場狀況與3D模擬情形-紅葉

紅葉橋現場狀況

無人機航拍與建模

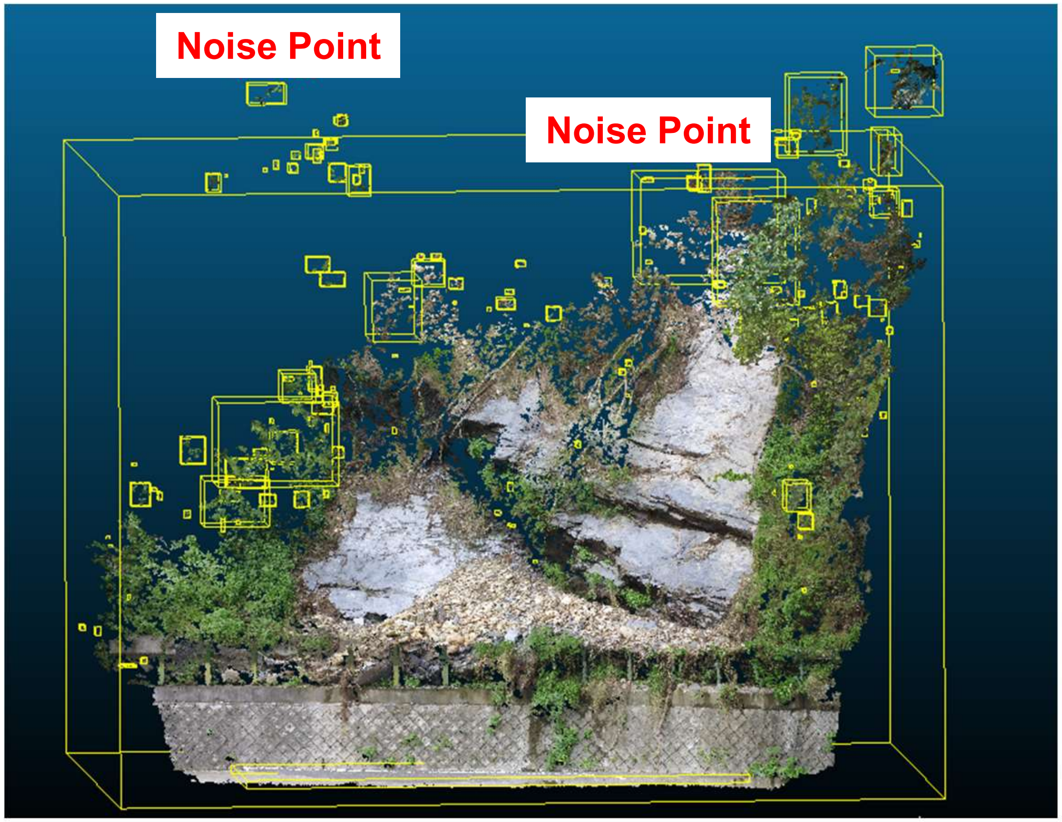


3D模擬情形

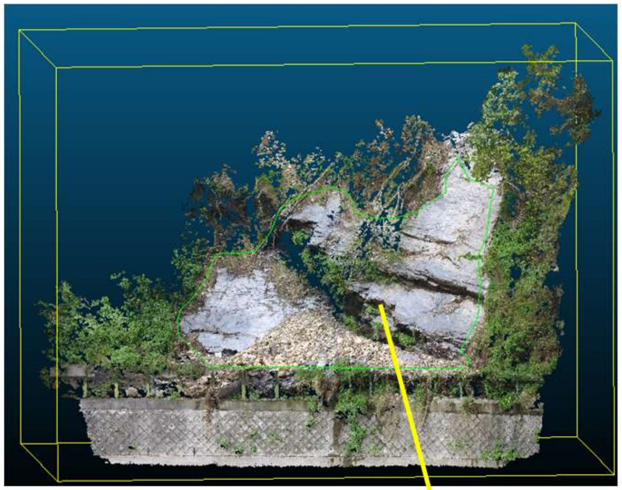


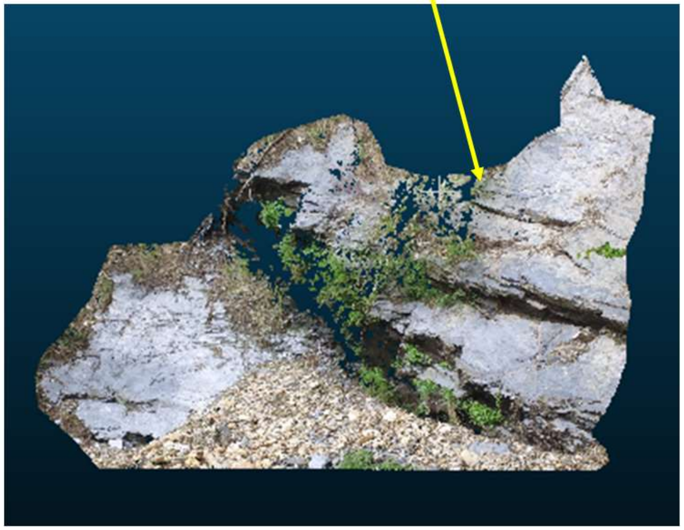
案例現場狀況與3D模擬情形-紅葉

離散點濾除

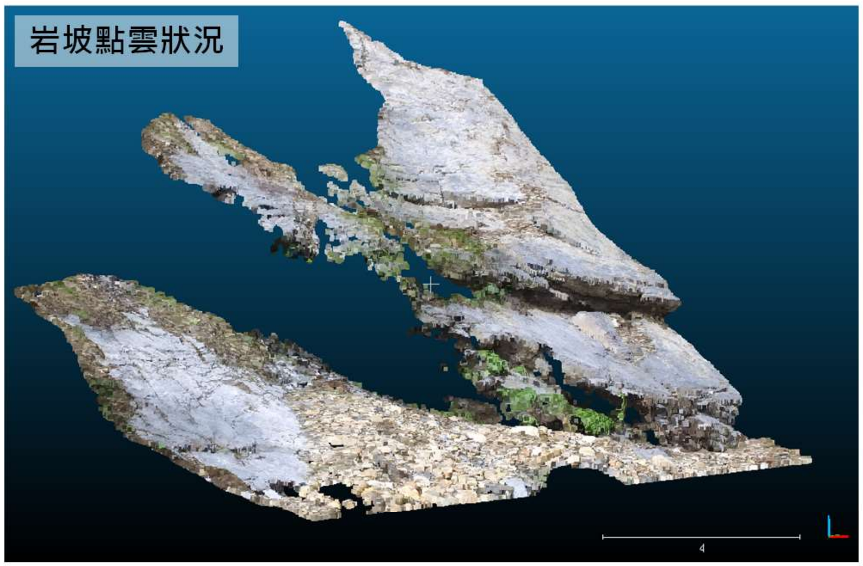


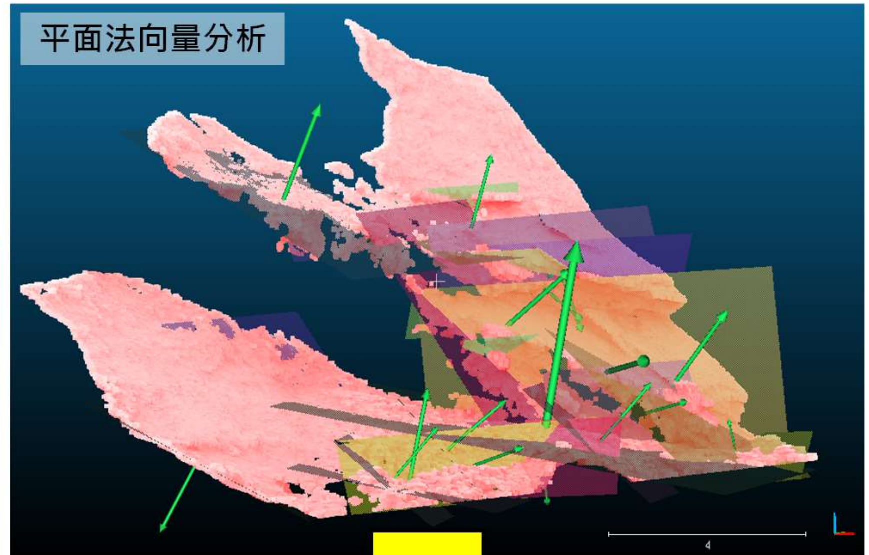
目標物擷取

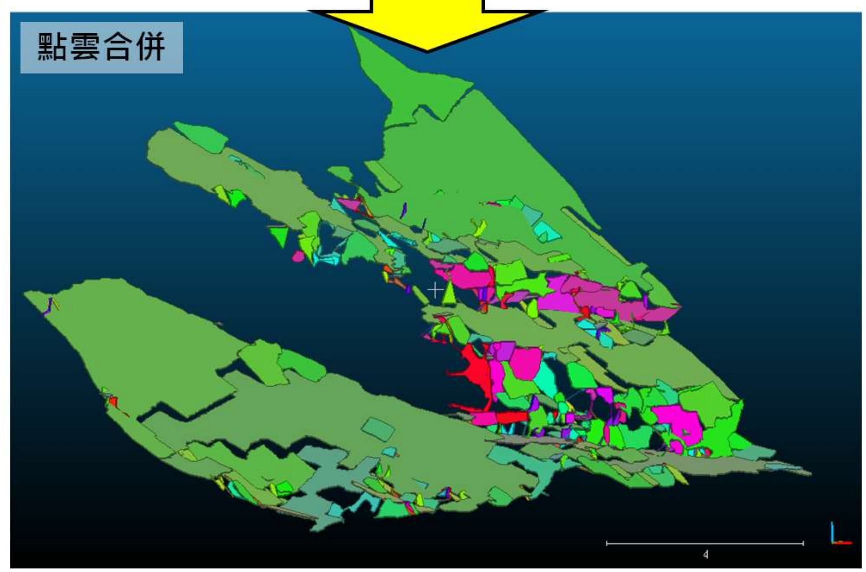




案例點雲法向量分析與點雲合併-紅葉

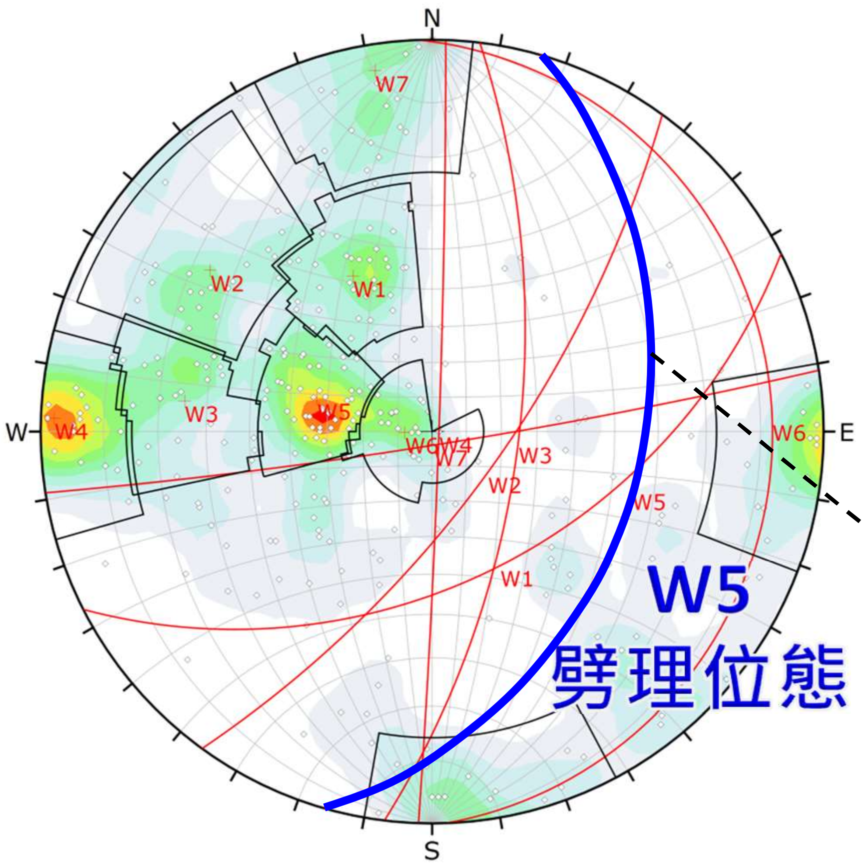






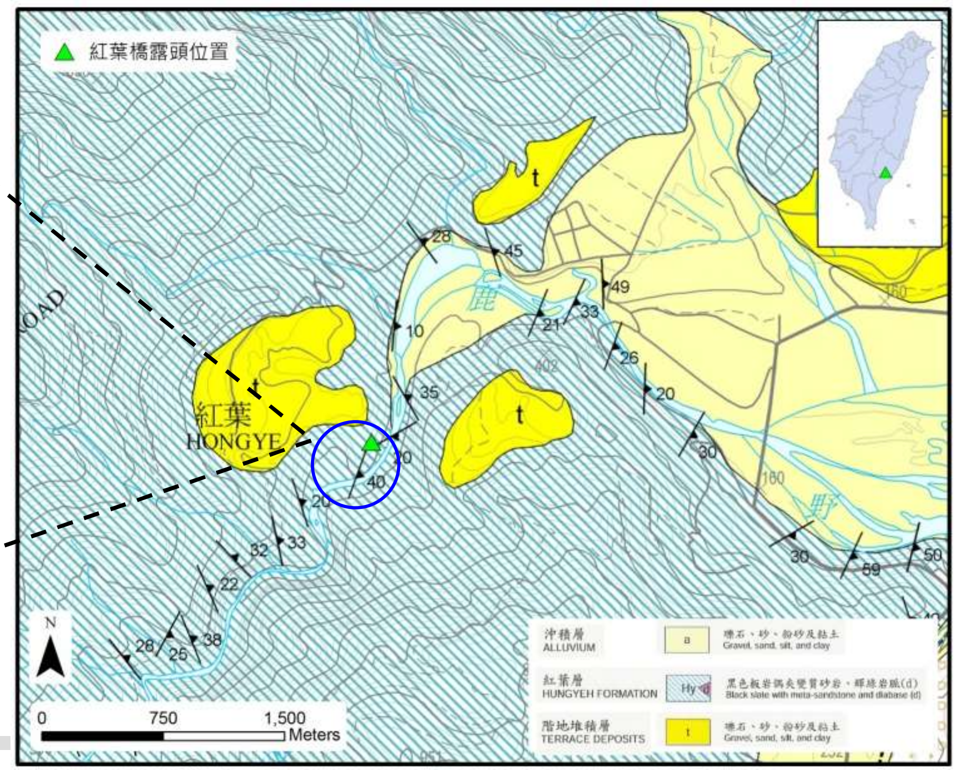
◆338,016個點雲決定出來313組弱面

案例赤平投影圓弱面分析與驗證-紅葉



Color	Density Concentrations
	0.00 - 0.60
	0.60 - 1.20
	1.20 - 1.80
	1.80 - 2.40
	2.40 - 3.00
	3.00 - 3.60
	3.60 - 4.20
	4.20 - 4.80
	4.80 - 5.40
	5.40 - 6.00
Contour Data	Pole Vectors
Maximum Density	5.70%
Contour Distribution	Fisher
Counting Circle Size	1.0%

ID	位態/傾角	ID	位態/傾角
W1	N63ºE/48ºS	W5	N16ºE/34ºS
W2	N36ºE/70ºS	W6	N2ºW/8ºS
W3	N7ºE/65ºS	W7	N81ºE/86ºS
W4	N2ºE/88ºS		



案例赤平投影圓弱面分析與驗證-紅葉

材料折減參數表

GSI	岩體材料	試驗彈性模數 E (Mpa)	Hoek&Brown破壞理論修正彈性模數 E (Mpa)	單壓強度 (Mpa)	摩擦角ø	岩性參數mi	擾動係數D
70	板岩	7000	3640	35	31.73	6	0

岩坡平面滑動潛勢分析

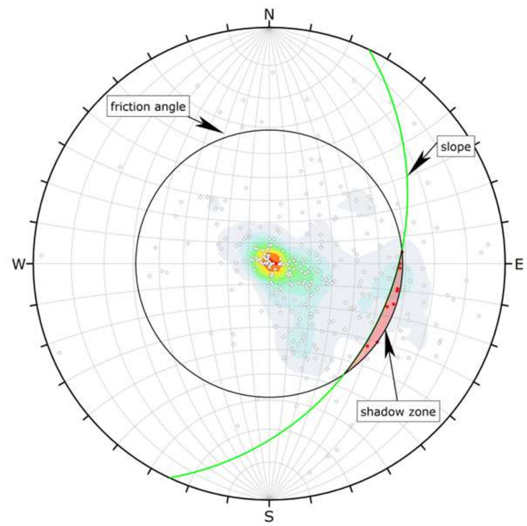
Color	Density Concentrations
	0.00 - 1.60
	1.60 - 3.20
	3.20 - 4.80
	4.80 - 6.40
	6.40 - 8.00
	8.00 - 9.60
	9.60 - 11.20
	11.20 - 12.80
	12.80 - 14.40
	14.40 - 16.00

Contour Data	Dip Vectors
Maximum Density	15.05%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Kinematic Analysis	Planar Sliding
Slope Dip	35
Slope Dip Direction	115
Friction Angle	31

	Critical	Total	%
Planar Sliding (All)	9	317	2.84%
Planar Sliding (Set 5: W5)	9	48	18.75%

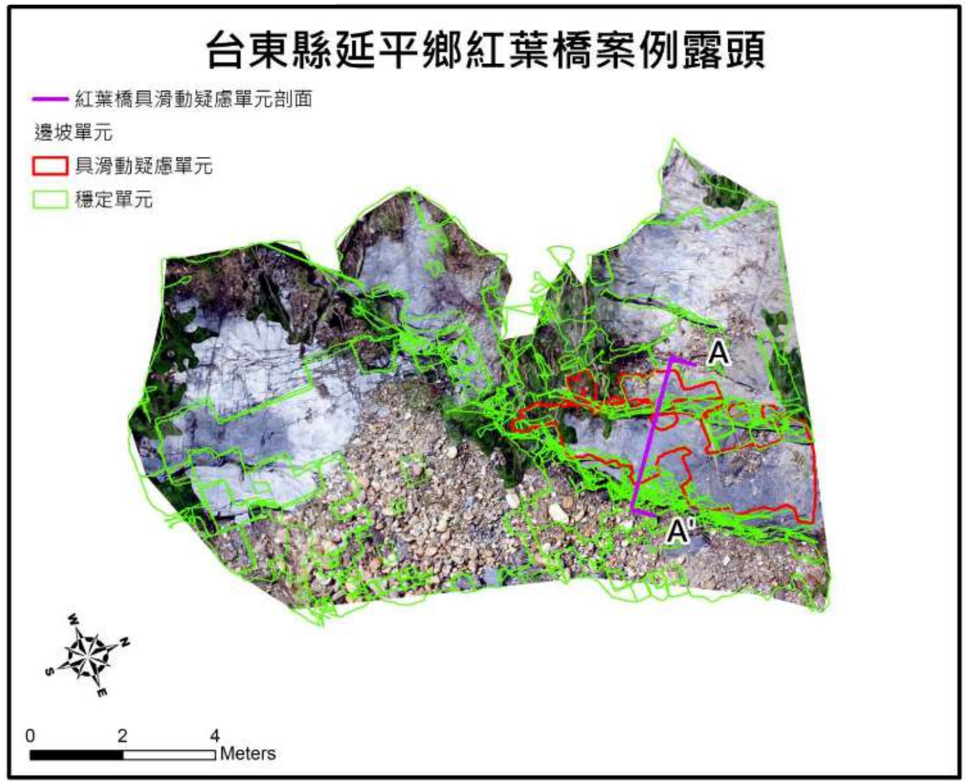
Plot Mode	Dip Vectors
Vector Count	317 (317 Entries)
Hemisphere	Lower
Projection	Equal Angle



平面型滑動潛勢弱面方位

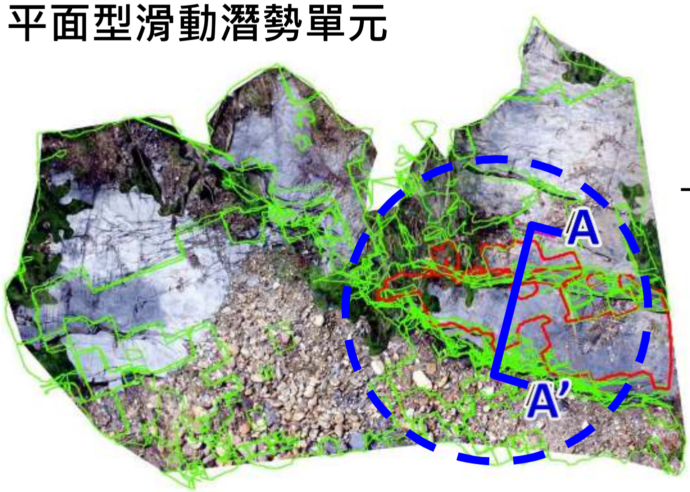
ID	位態/傾角	ID	位態/傾角
F1	N85°W/31°S	F6	N40°E/33°S
F2	N89°E/32°S	F7	N11°E/32°S
F3	N36°E/31°S	F8	N18°E/32°S
F4	N20°E/34°S	F9	N90°E/32°S
F5	N90°E/32°S		

平面型滑動潛勢單元



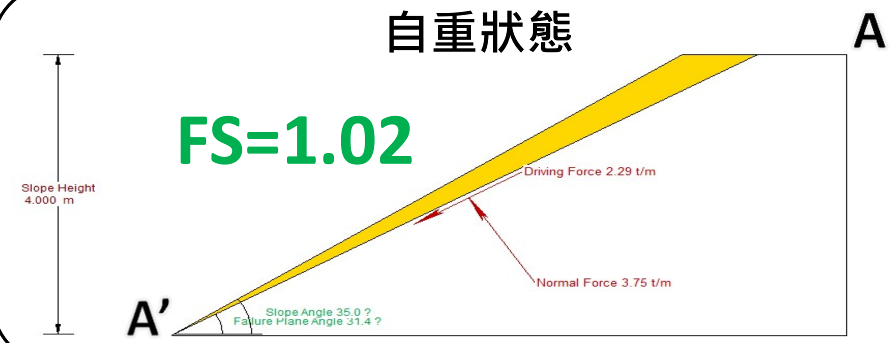
岩坡平面滑動穩定分析-紅葉

平面型滑動潛勢單元

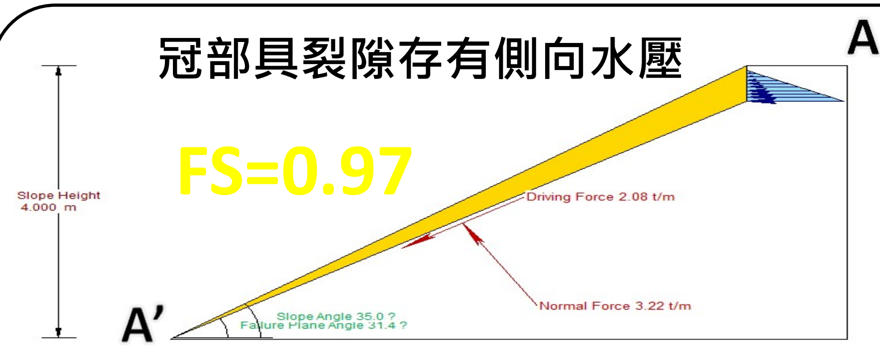


狀態	參數		安全係數Fs
自重狀態	邊坡角度(度)	35	1.02
	坡高(m)	4	
	單位重(t/m3)	2.6	
	滑動面角度(度)	31.38	
	摩擦角(度)	31.73	
冠部具裂隙存有側向水壓	靜水壓單位重(t/m3)	0.981	0.97
冠部具裂隙存有側向水壓+地震力	水平地震係數	0.24	0.6

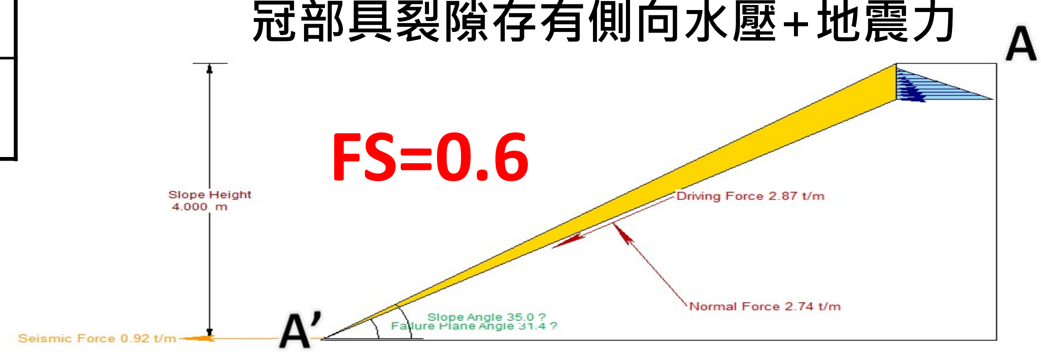
自重狀態



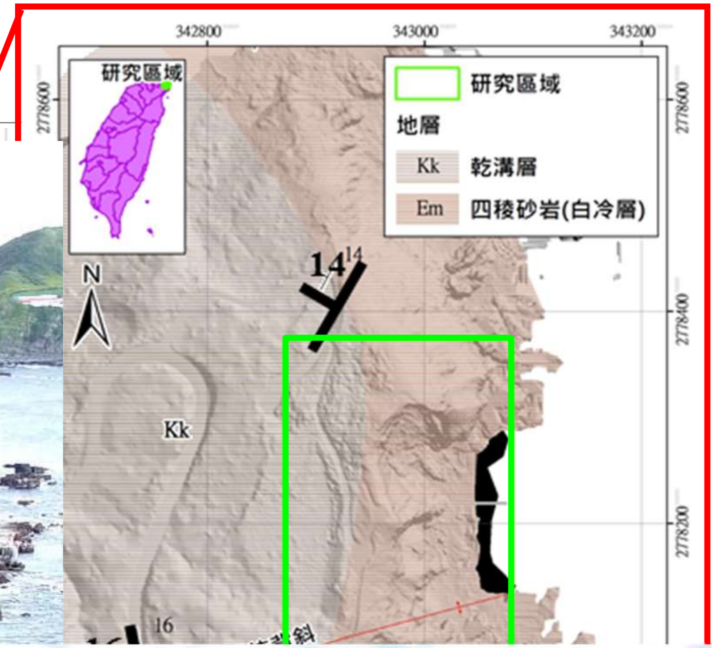
冠部具裂隙存有側向水壓

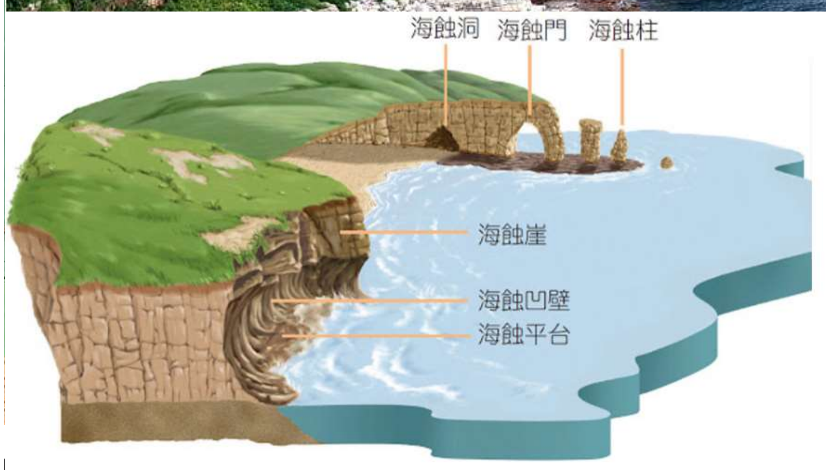


冠部具裂隙存有側向水壓+地震力



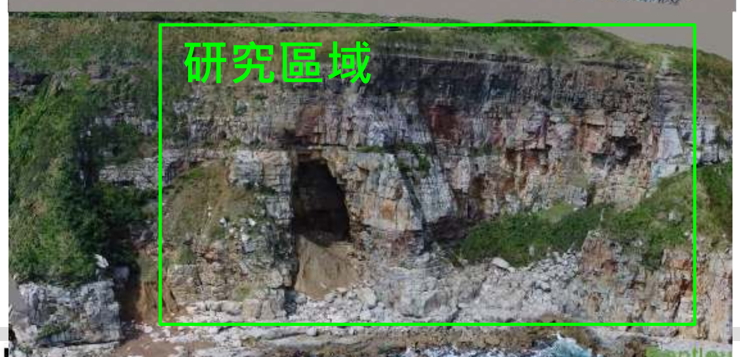
研究區域簡介與掃瞄儀器說明



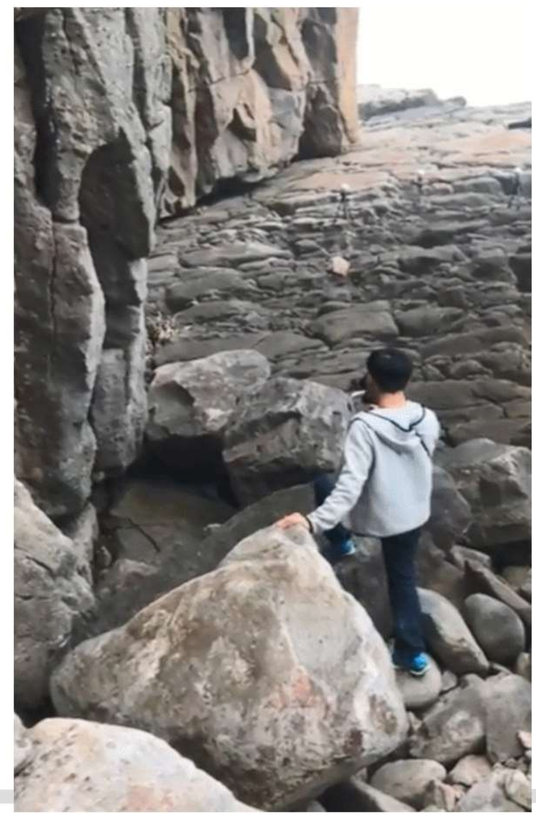


研究區域簡介與掃瞄儀器說明

無人載具攝影測量建置三維模型展示



手持移動式掃瞄儀GeoSLAM ZEB-REVO RT簡介



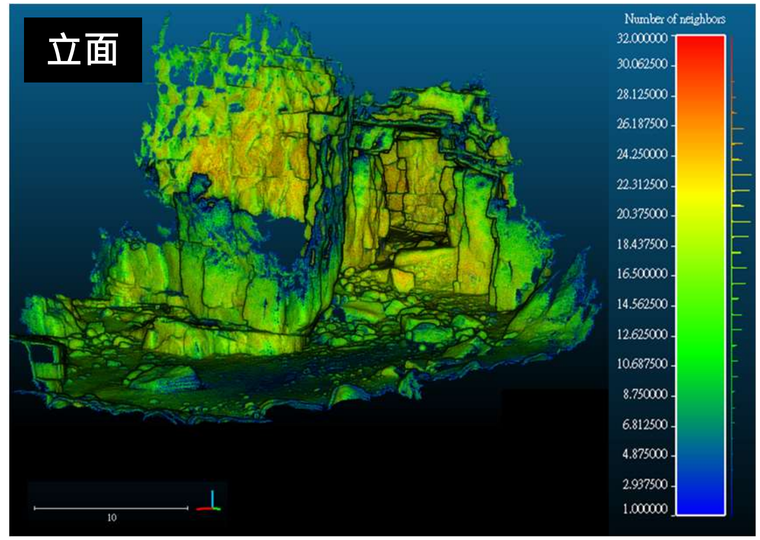
手持式掃瞄儀參數與掃瞄成果說明

手持移動式掃瞄儀GeoSLAM ZEB-REVO RT技術參數

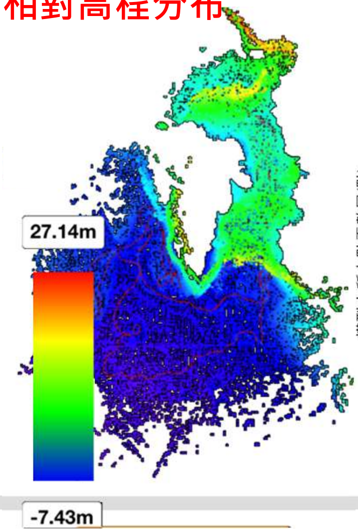
性能特點	最大測距	30m
	數據獲取速率	43,200點/秒
	分辨率	水平0.625度 垂直1.8度
	視場角	360度
	運載平台	手持/車/機載
數據特點	通用性	兼容所有主流CAD軟體
	圖形化用戶展示介面	兼容市用平板或手機
系統精度	相對精度	±1cm
	絕對精度	3~30cm
傳感器資訊	雷射波長	905nm
	掃瞄線速率	100Hz
	旋轉速率	0.5Hz
電池資訊	電池類型	鋰電池
	容量	90Wh
	工作時間	3~4hr
重量	電池重量	550g
	機身重量	1kg

利用手持式光達掃瞄儀ZEB-REVO RT針對龍洞海蝕洞穴進行掃瞄後，耗費時間共16分鐘獲取點數計5,782,282點；掃瞄建構之體積為7,766m^3、表面積則為1,305m^2。100cm^2內之點雲密集程度進行統計分析，顯示整體模型80%，每100cm^2可獲取14個點，解析度低於7cm^2。

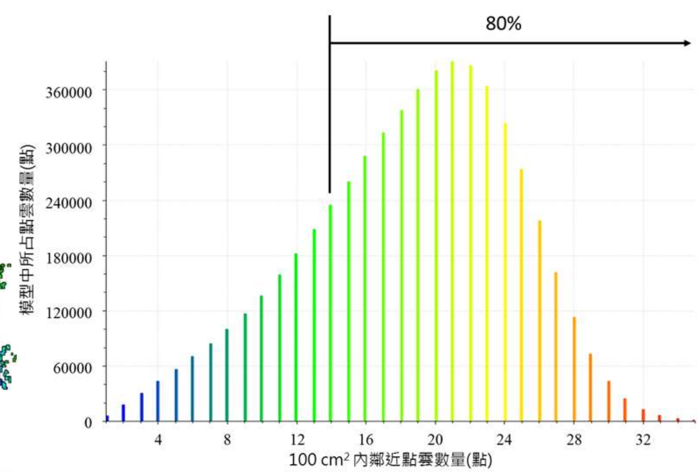
點雲密集程度展示圖



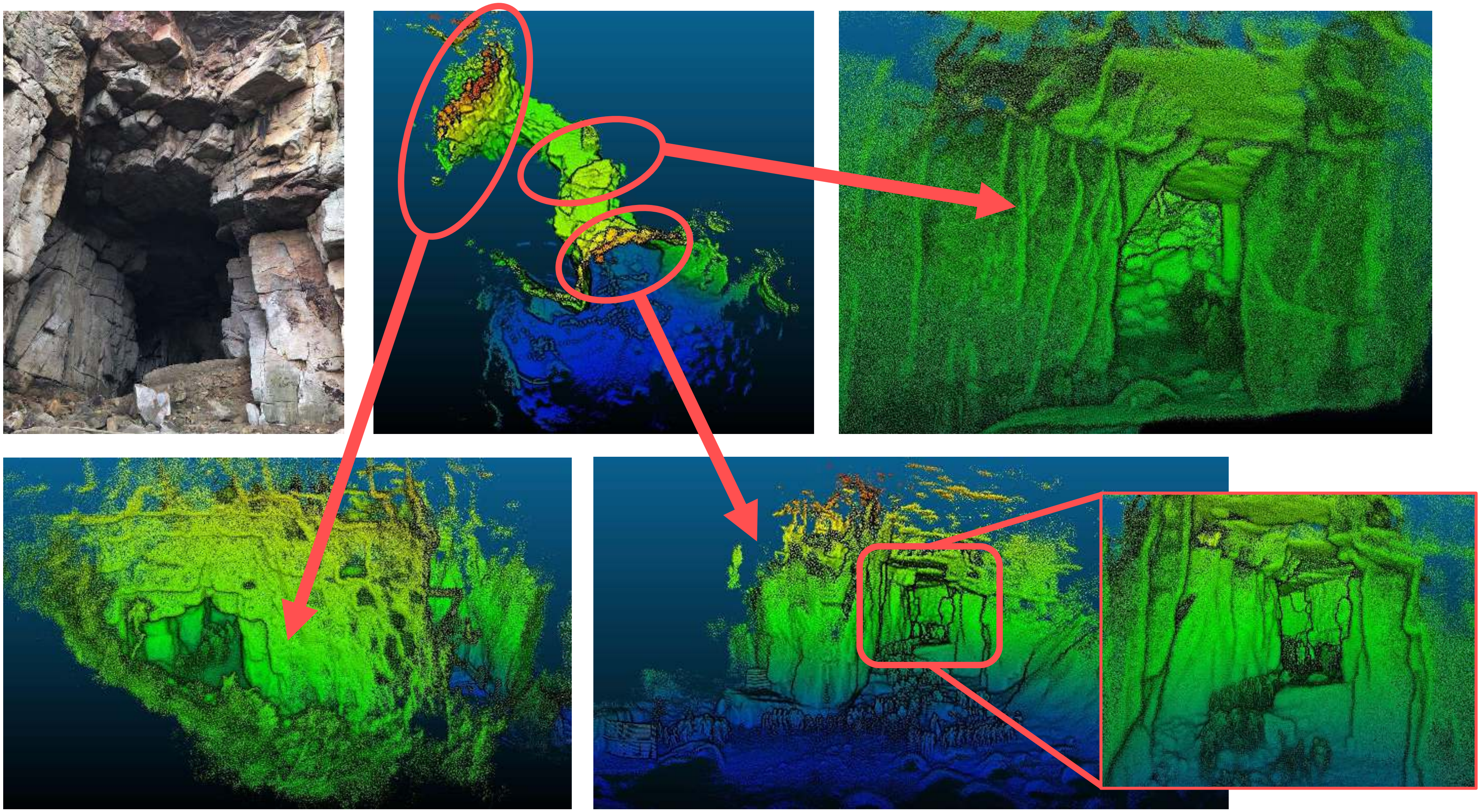
相對高程分布



100cm^2內鄰近點雲數量統計狀況

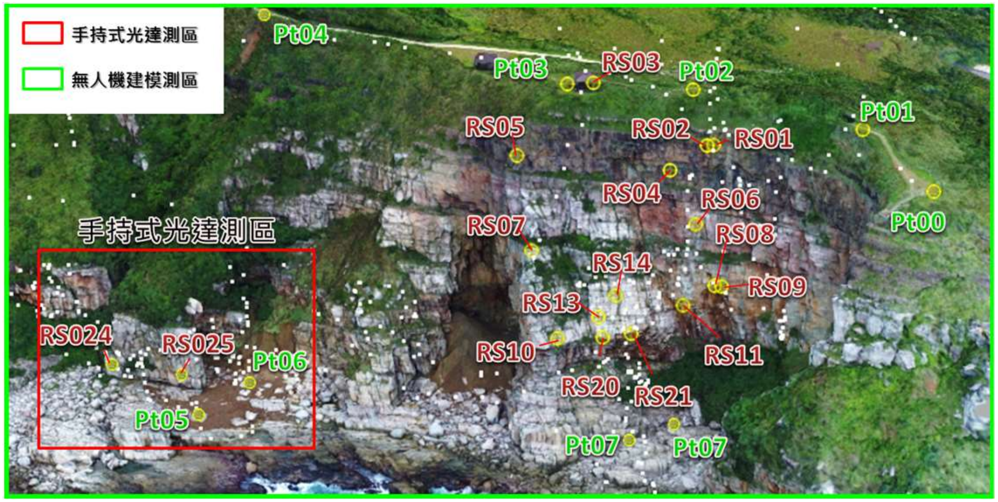


手持式光達掃瞄成果



地面與側壁控制點設置

地面與側壁控制點分布圖(RS側壁控制點、Pt地面控制點)



VBS-RTK地面控制點與精度一覽表(TWD97)

Name	N	E	Z	Nrms	Erms	Zrms
Pt0	2778324.22	342983.73	94.84	0.003	0.003	0.009
Pt1	2778298.63	342962.62	99.83	0.004	0.005	0.011
Pt2	2778239.64	342939.97	93.48	0.004	0.005	0.012
Pt3	2778205.05	342957.72	97.46	0.004	0.005	0.012
Pt4	2778086.47	342931.94	111.64	0.004	0.003	0.008
Pt5	2778113.75	343034.93	4.76	0.005	0.004	0.011
Pt6	2778120.5	343018.93	5.15	0.003	0.004	0.015
Pt7	2778243.54	343000.59	3.33	0.005	0.004	0.016
Pt8	2778261.42	342997.65	10.92	0.003	0.004	0.007

※單位：公尺
灰底欄位為手持式光達掃瞄區位所用之控制點。

中海達V30 VBS-RTK

PENTAX R-425VN 免稜鏡紅外線光波全測站

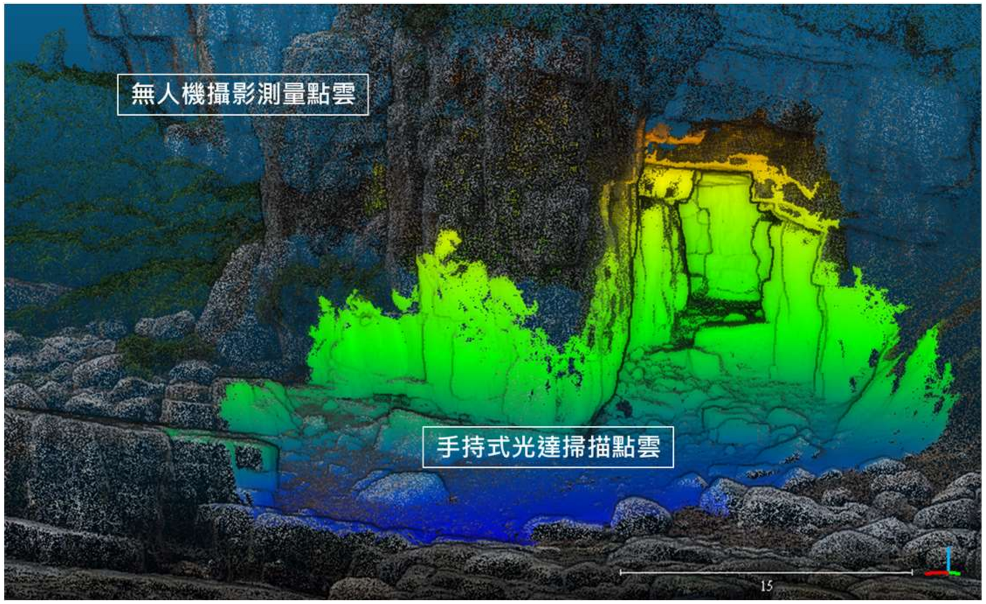
全測站側壁控制點與精度一覽表(TWD97)

Name	N	E	Z	測距(D)	空間精度
RS01	2778252.24	342958.73	85.51	69.716	±0.006
RS02	2778250.74	342960.19	85.76	70.234	±0.006
RS03	2778215.38	342961.76	101.13	101.838	±0.007
RS04	2778239.93	342962.36	76.7	80.225	±0.007
RS05	2778197.54	342978.79	81.86	115.552	±0.007
RS06	2778288.07	342968.69	84.97	35.982	±0.006
RS07	2778206.47	342990.33	57.3	111.044	±0.007
RS08	2778248.38	342962.75	60.18	78.096	±0.007
RS09	2778274.08	342965.04	69.34	53.422	±0.006
RS10	2778217.92	342999.07	34.18	110.727	±0.007
RS11	2778257.56	342964.57	41.46	80.652	±0.007
RS13	2778226.08	342986.56	36.34	102.955	±0.007
RS14	2778229.57	342981.21	41.64	97.755	±0.007
RS20	2778234.55	342981.22	29.28	71.644	±0.006
RS21	2778237.22	342978.62	28.95	72.216	±0.006
RS24	2778076.25	343027.53	13.43	78.814	±0.007
RS25	2778099.75	343026.03	11.59	82.599	±0.007

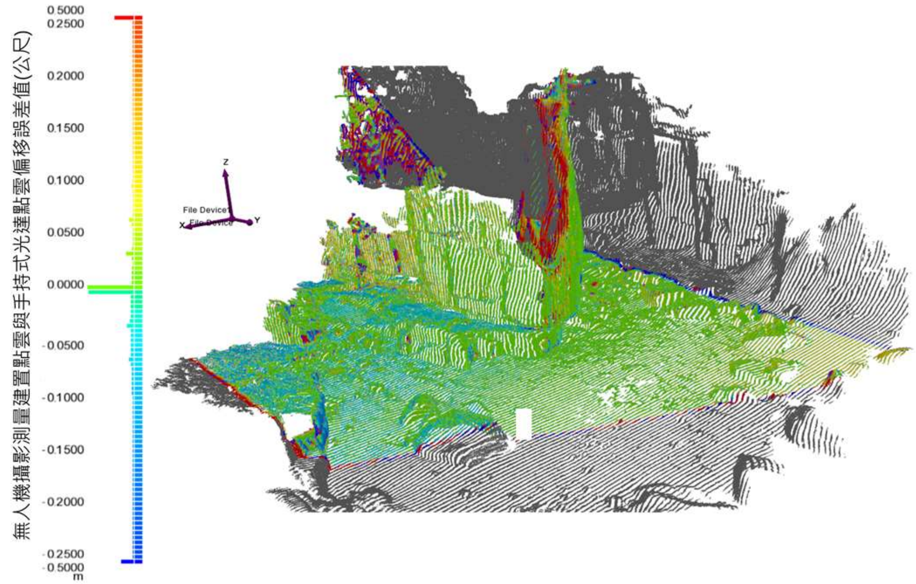
※儀器精度± (5 + 2 ppm x 側距D) mm，單位：公尺
灰底欄位為手持式光達掃瞄區位所用之控制點。

手持式光達點雲與攝影測量獲取點雲比對

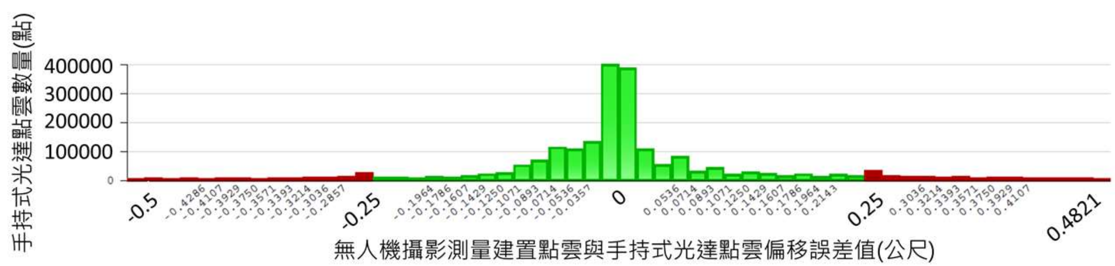
無人機攝影測量點雲整合手持式光達點雲模型示意圖



無人機攝影測量點雲整合手持式光達點雲模型對位點雲偏移量



無人機攝影測量點雲整合手持式光達點雲模型對位誤差統計

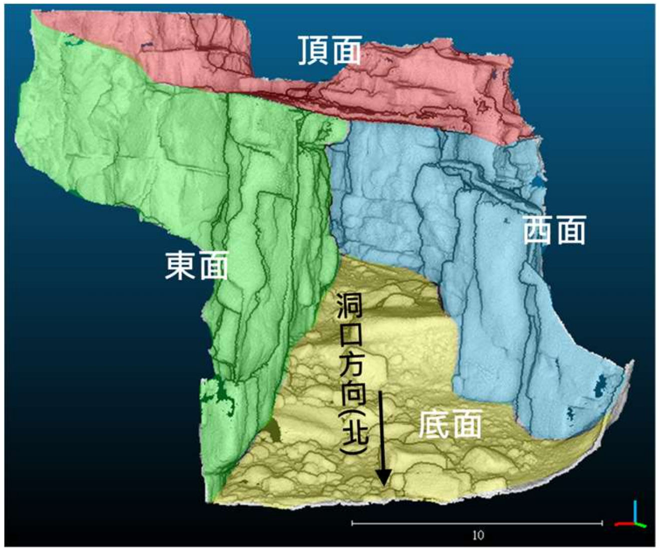


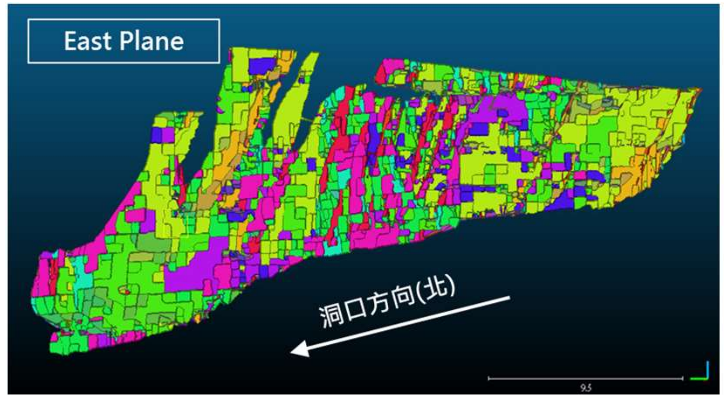
Highest			●	0.5000	Lowest			●	-0.5000
Below -0.2500	100970	In Tol.	1801289	Above 0.2500	140086	Avg.	0.0057	Max.	0.5000
	4.94%		88.20%		6.86%	Std. Dev.	0.1384	RMS	0.1385

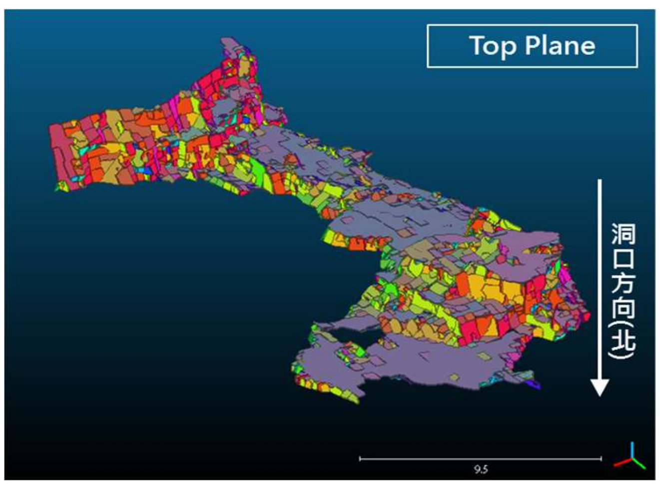
兩種採集方式之點雲模型，本研究利用FARO儀器測繪公司開發之BuildIT Construction軟體進行對位以及誤差校正之作業，以提升整體模型精度供後續分析之用。經對位後可見兩者模型誤差值大致介於±25公分，佔整體模型比例88.2%；該統計結果又以±2公分所佔比例最高。

點雲資料與地質不連續面量測之轉換

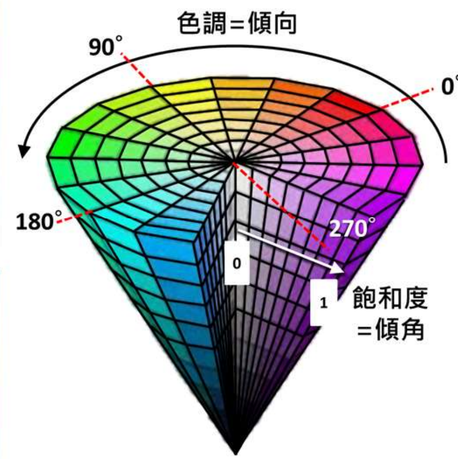
手持式光達掃瞄模型分區示意圖







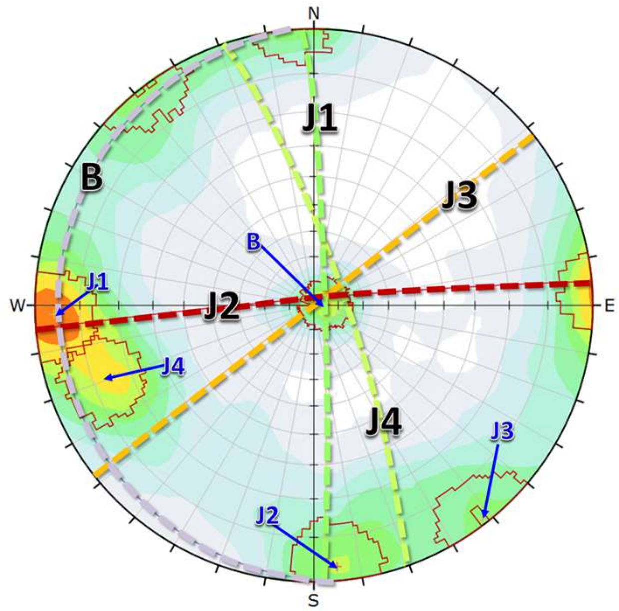
HSV模型與不連續面位態資訊分布關係圖

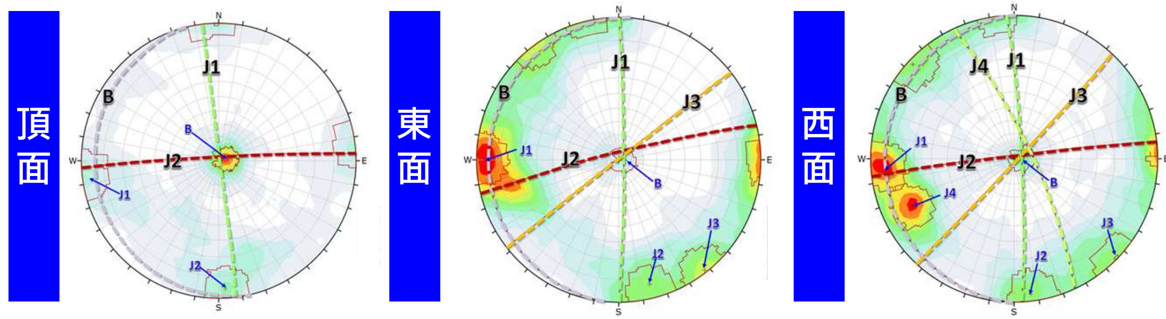


針對海蝕洞穴內之頂面、東面以及西面分別進行不連續面自動分析作業，總計共獲取5953個不連續面分析單元，不連續面位態將根據立體彩色模型(HSV)定義之。其色調代表為位態之傾向(dip direction)，而飽和度則代表為位態之傾角(dip angle)。

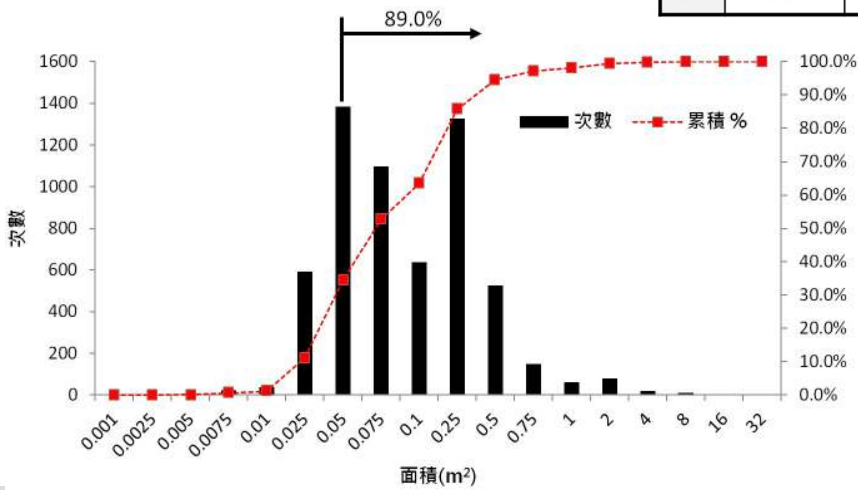
點雲資料與地質不連續面量測之轉換

不連續面位態赤平投影圖-整體模型





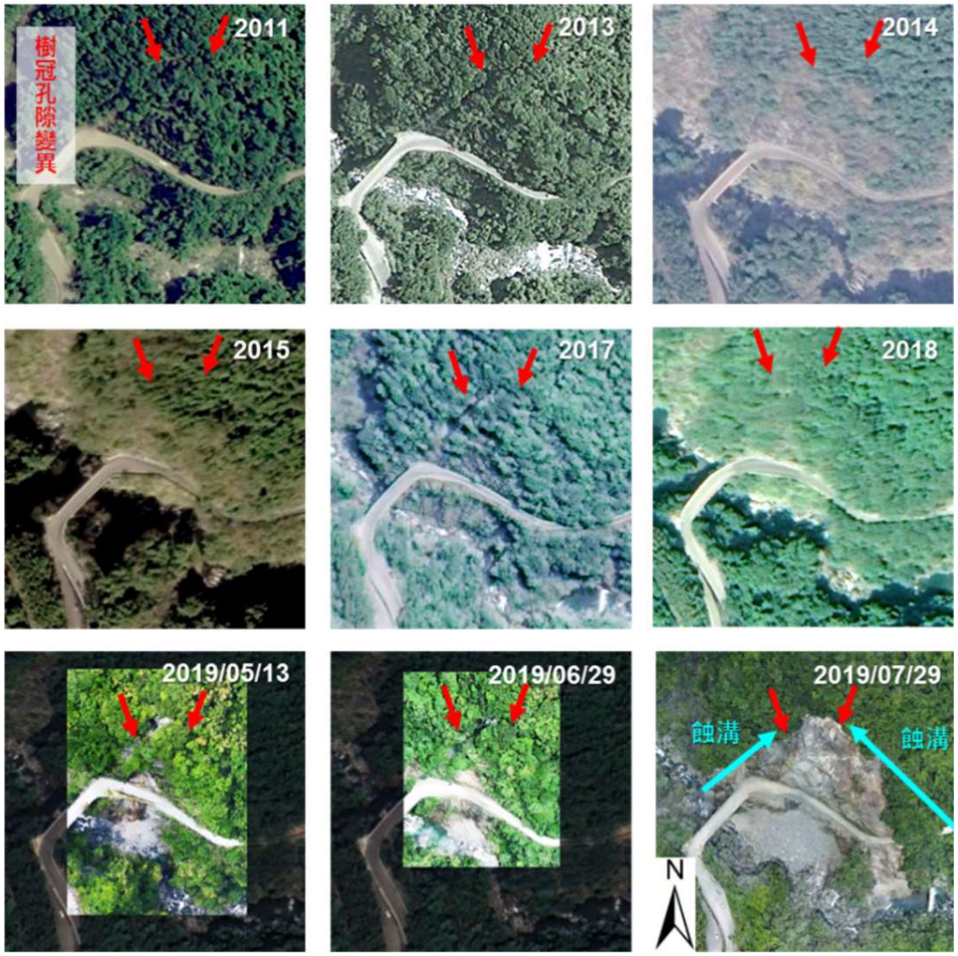
ID	Dip	Dip Direction	走向/傾角
B	5	265	N5度W/5度SW
J1	86	88	N2度W/86度NE
J2	87	355	N85度E/87度NW
J3	89	322	N52度E/89度NW
J4	77	71	N19度W/77度NE



自動判釋不連續面之表面積過小，可能會有失去代表性之可能，故針對分析後獲取之不連續面表面積累積比例進行統計，在瞭解其分析結果之表面積分布後，取該統計模型中佔近九成比例，也就是不連續面分析單元表面積大於0.05m2將視為可進行地質統計之數據，經篩選後共獲取3910個不連續面分析單元。

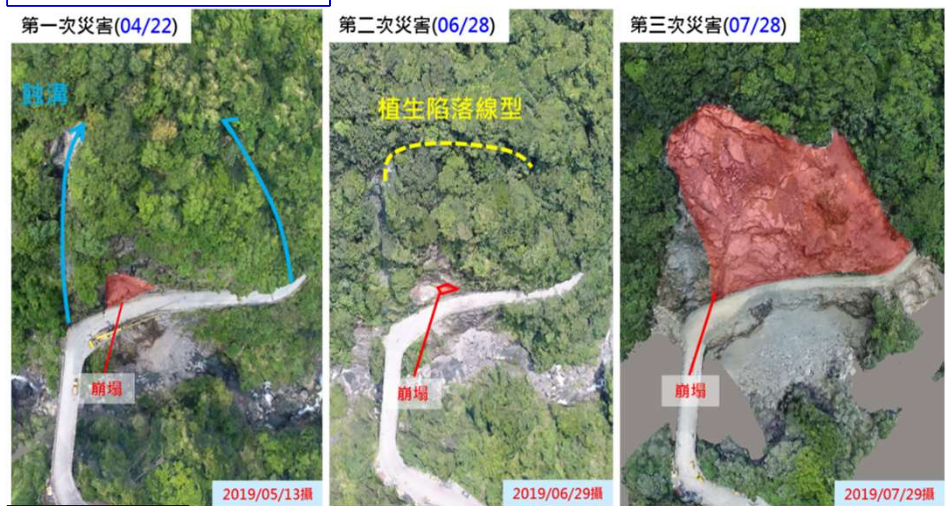
岩坡破壞運動學機制分析-台7線32K+500

2011年至2019年Google Earth歷史衛星影像與UAV正射影像進行樹冠孔隙變異判釋



UAV航拍時間	2019/05/13	2019/06/29	2019/07/29
災害發生時間編號次數	第一次災害 2019/04/22	第二次災害 2019/06/28	第三次災害 2019/0728

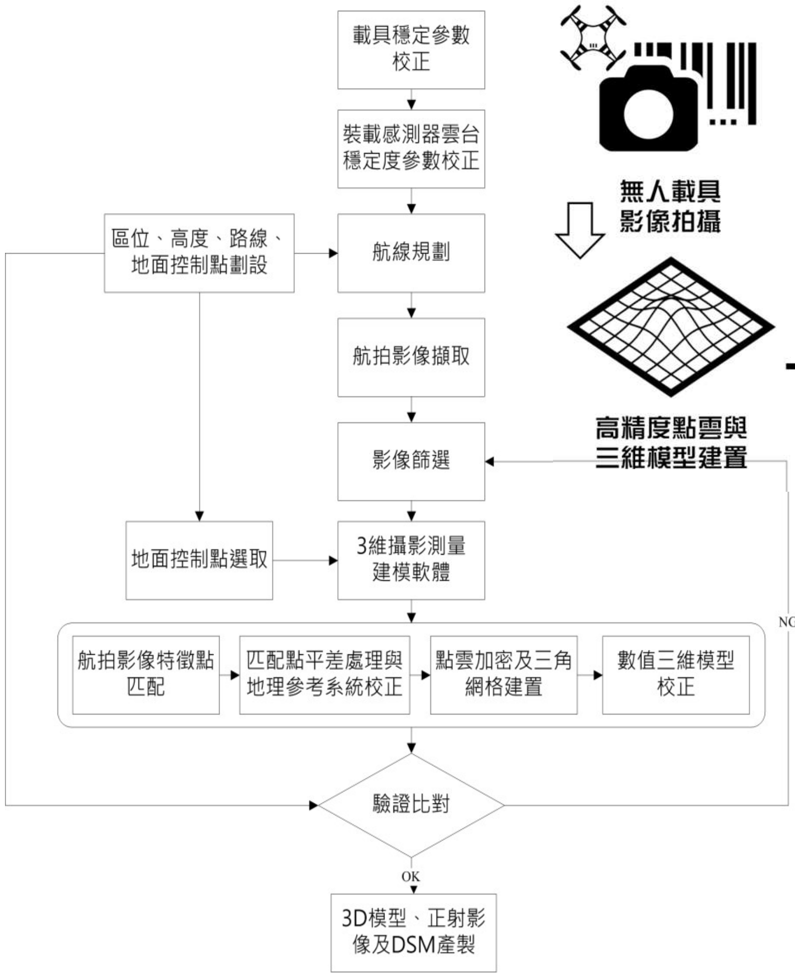
正射影像與地貌變異

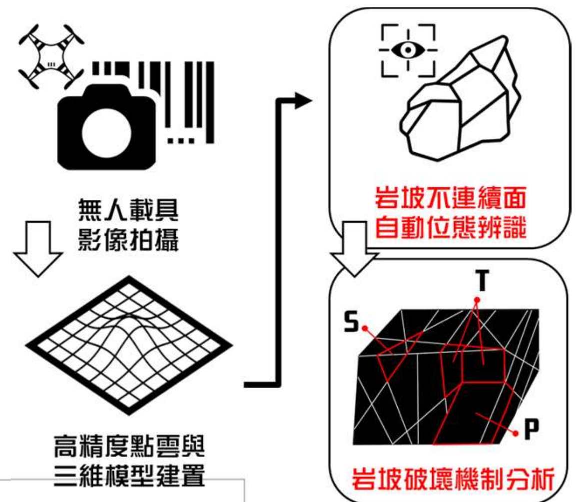


立體模型

岩坡破壞運動學機制分析-台7線32K+500

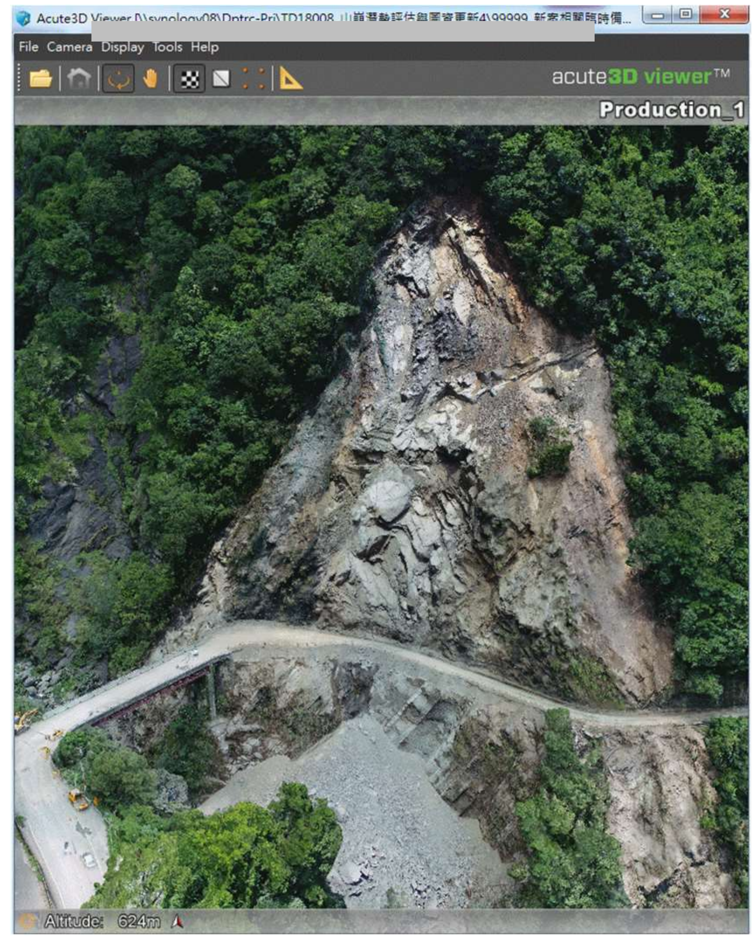
UAV點雲、模型建置與運動學機制分析流程





第二次災後模型
(2019/06/29攝)

第三次災後模型
(2019/07/29攝)

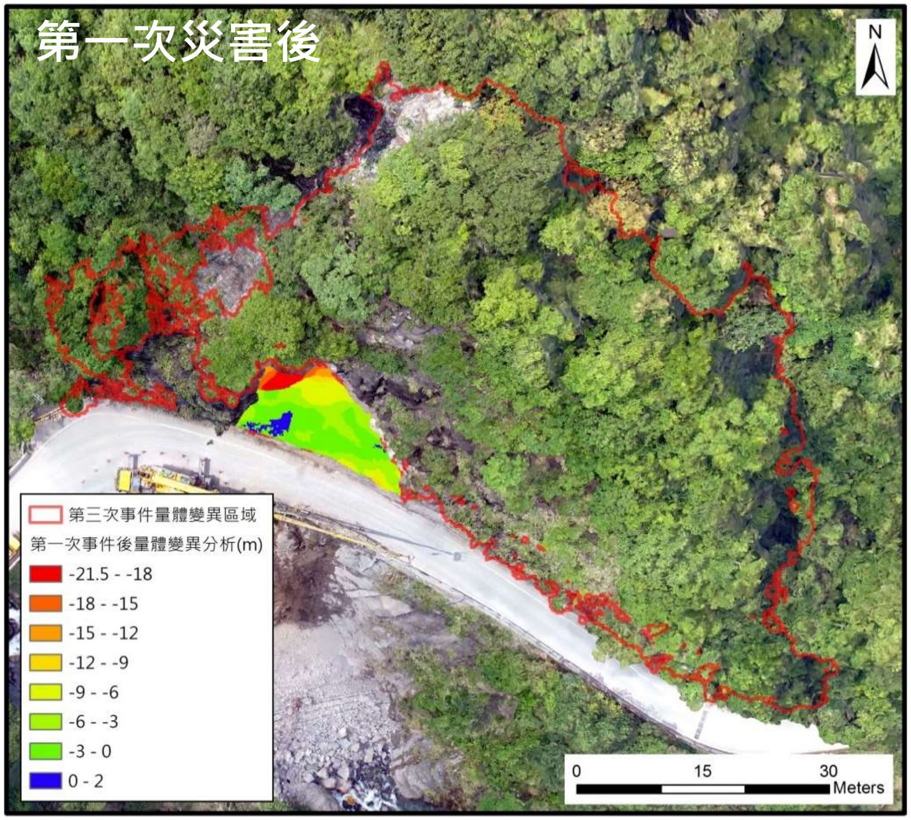


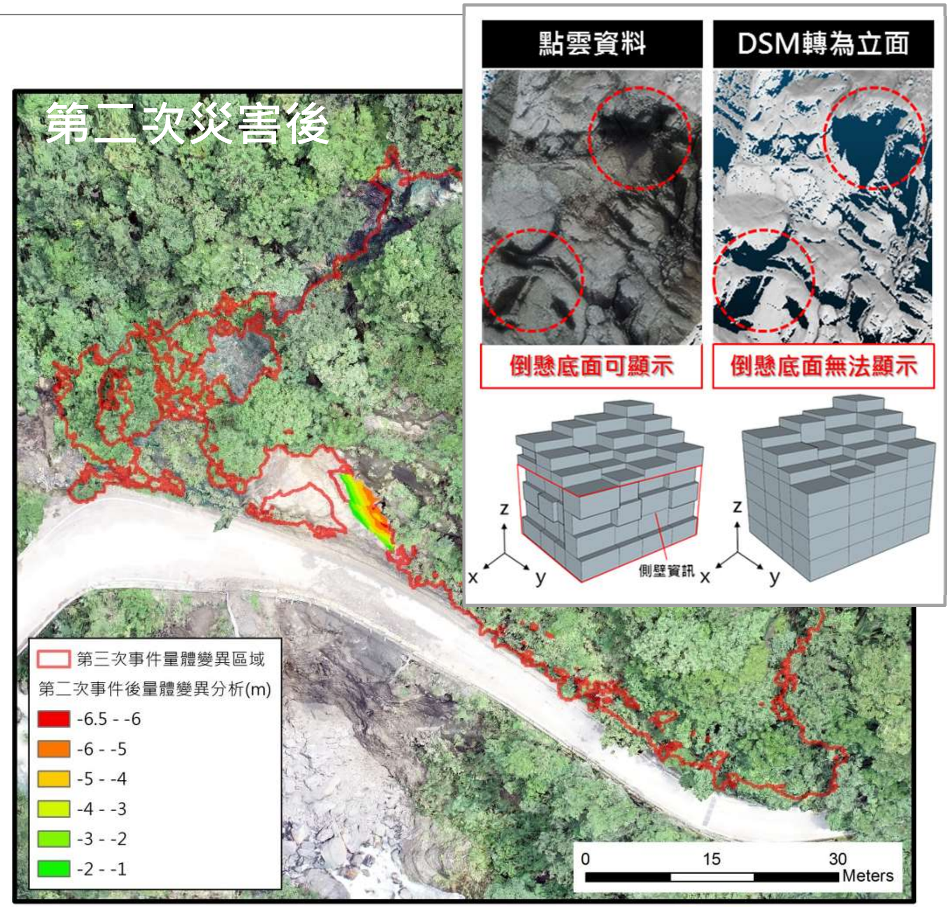
ContextCapture

acute3D capturingreality

影像判釋及變異分析-台7線32K+500

災害位置與量體評估分析

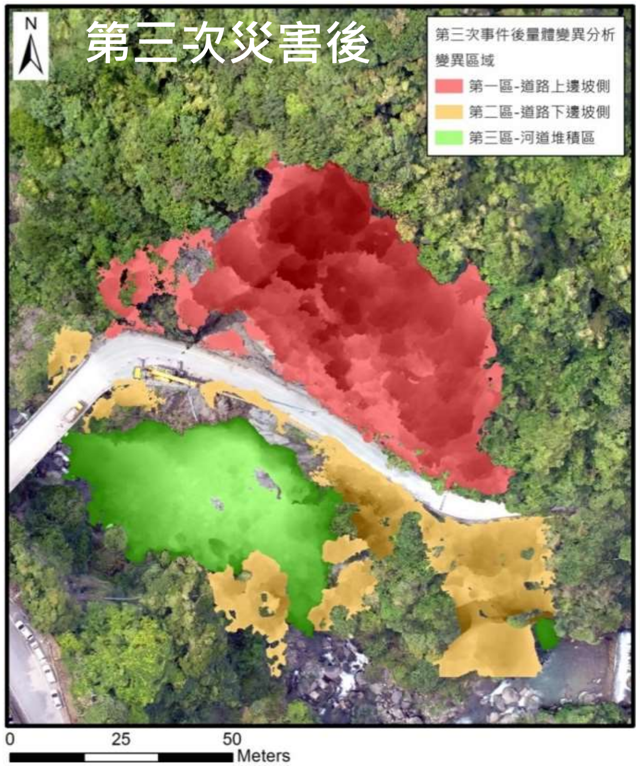


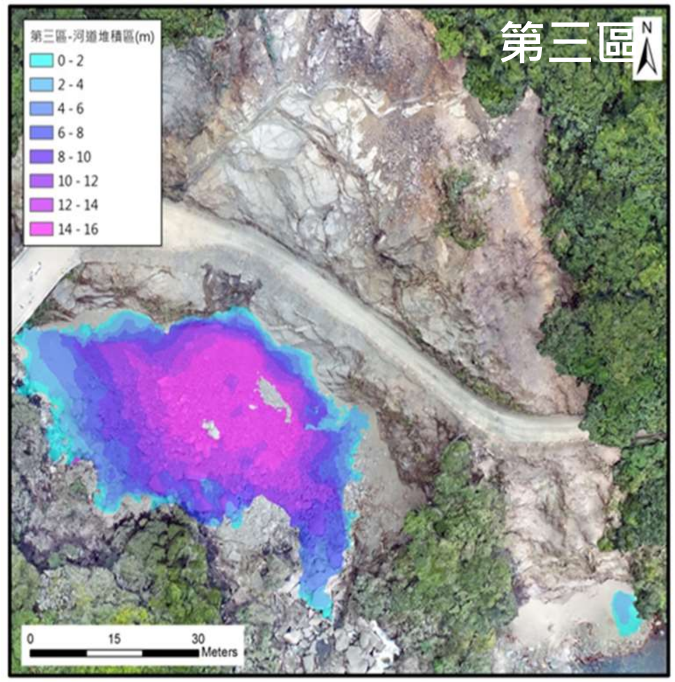


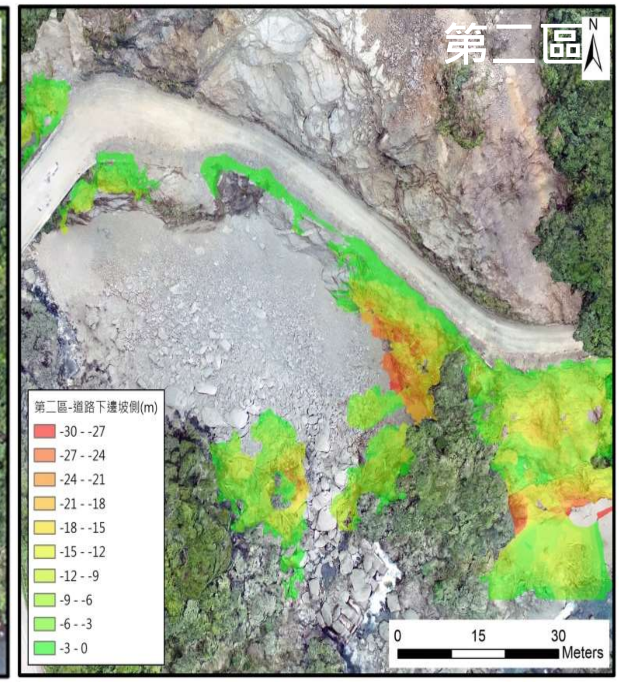
災害發生時序	量體變異計算(m^3)	特別狀況說明
第一次災害2019/04/22	-673.4	-
第二次災害2019/06/28	-118.6(-79.6*註)	註：DSM相加減分析成果。 實際狀況應屬倒懸內凹之塊體損失狀況，處理時應以點雲資料或是3D模型計算量體損失，經以3D模型量測實際應損失118.6m^3

影像判釋及變異分析-台7線32K+500

災害位置與量體評估分析

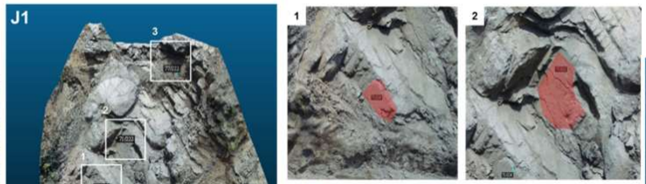






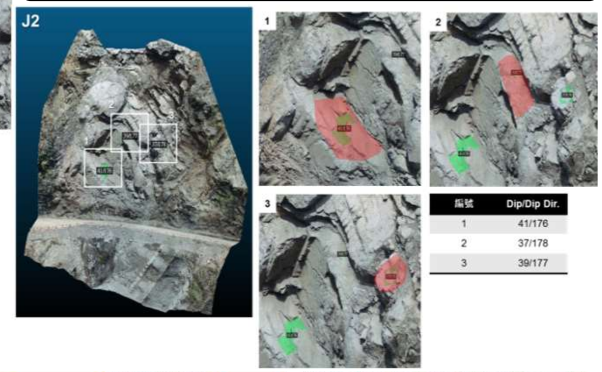
災害發生時序	量體變異計算(m^3)			特別狀況說明
第三次災害 2019/0728	第一區- 道路上邊坡側	-46,646.1	-59962.6	最大量體損失位置為災前左右側蝕溝之源頭區；下邊坡側應注意榮華橋之量體損失位置與橋台穩固之關係；河道堆積量體已推擠於對岸側，故可能一度有受阻塞之情形。
	第二區- 道路下邊坡側	-13,316.5		
	第三區- 河道堆積	+14,704.7		

現場調查配合點雲不連續面判釋-台7線32K+500

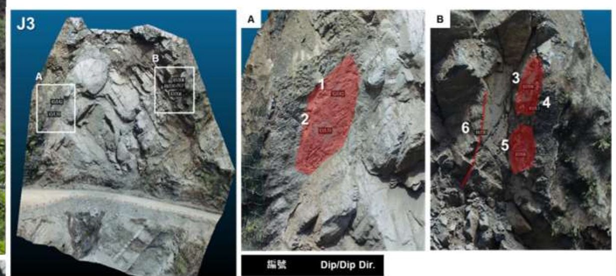


編號	Dip/Dip Dir.
1	71/222
2	71/224
3	77/222

Virtual Compass插件手動選取

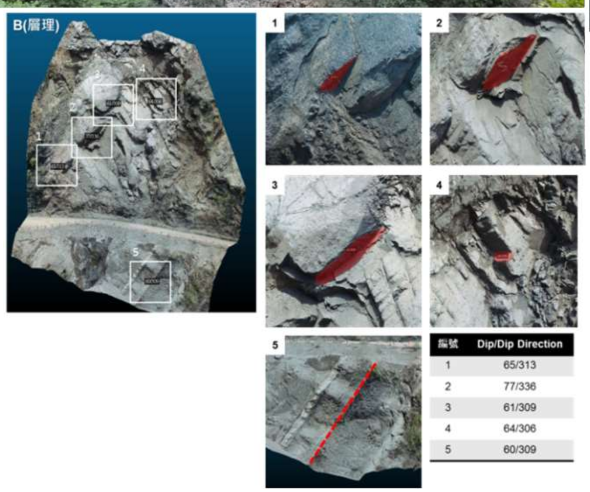


編號	Dip/Dip Dir.
1	41/176
2	37/178
3	39/177

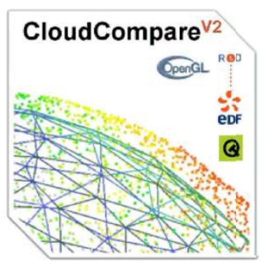


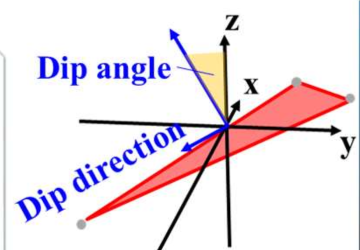
編號	Dip/Dip Dir.
1	82/142
2	83/139
3	83/306
4	85/304
5	85/313
6	88/330

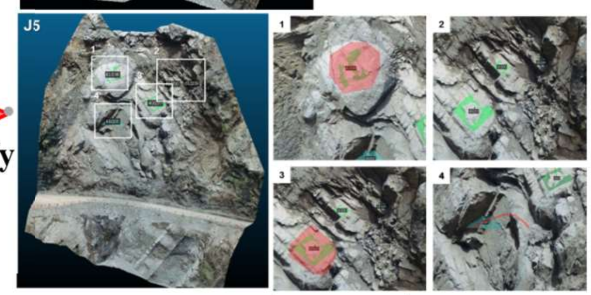
編號	Dip/Dip Dir.
1	13/349



編號	Dip/Dip Direction
1	65/313
2	77/336
3	61/309
4	64/306
5	60/309

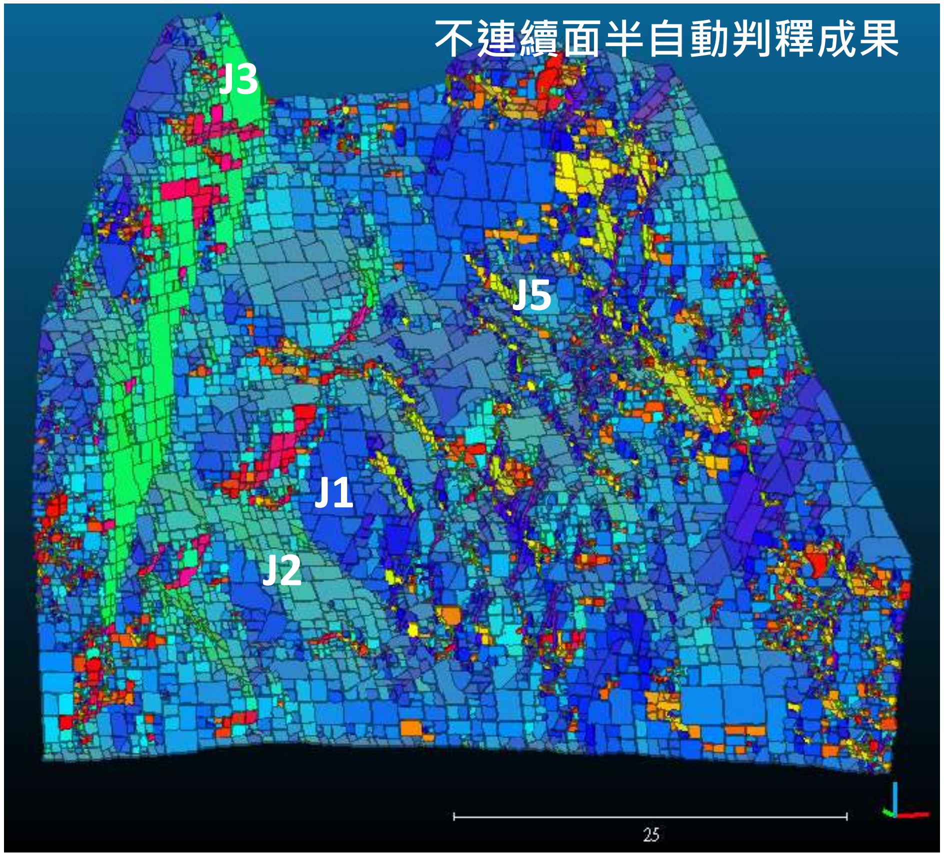






編號	Dip/Dip Dir.
1	48/205
2	41/198
3	40/210
4	41/200

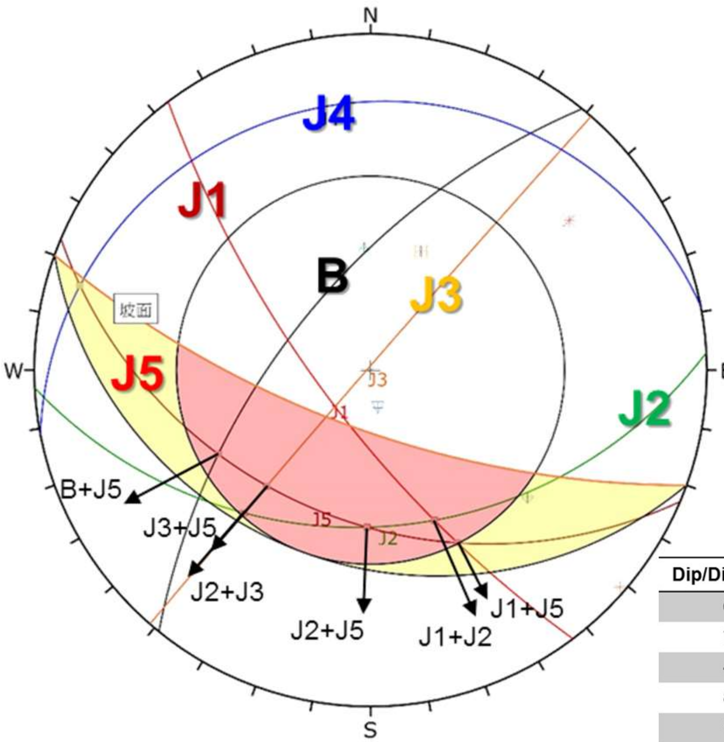
岩坡破壞運動學機制分析-台7線32K+500



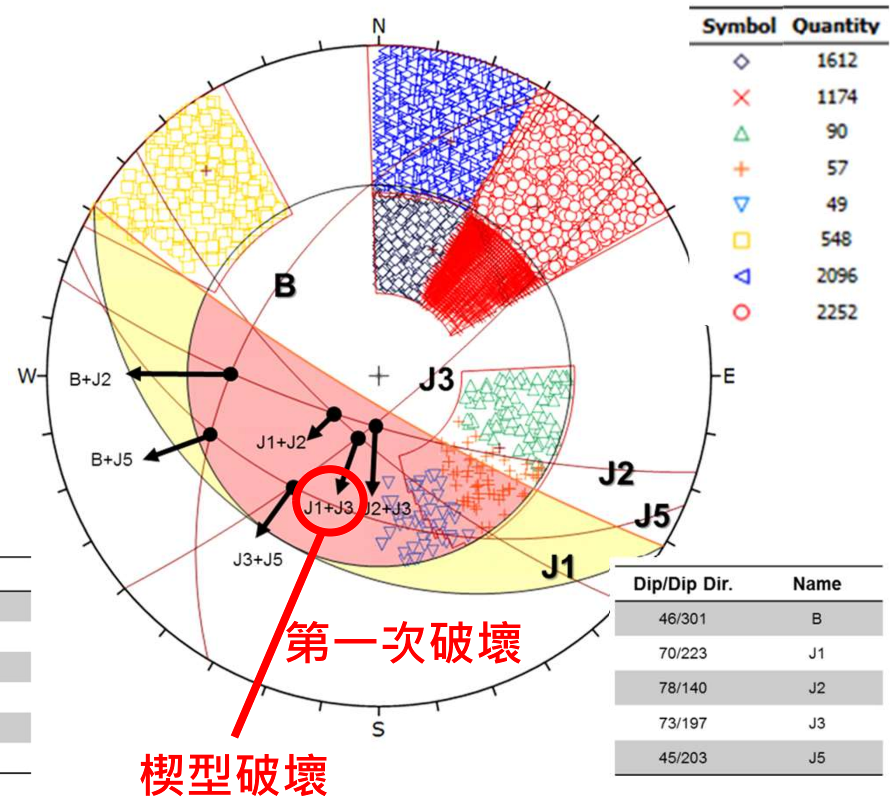
不連續面半自動分析方法，會**受非岩石邊坡**之雜訊**干擾**，故於分析之前需施作非岩坡點雲之**濾除動作**，而濾除後之岩坡點雲與FACETS：Kd-tree半自動判釋成果，**整體坡面分析**之表面積為**2,305平方公尺**，而**FACETS：Kd-tree半自動判釋**總計共獲取**13,415個不連續面分析單元**，不連續面位態將根據立體彩色模型(HSV)定義之。

岩坡破壞運動學機制分析-台7線32K+500

Virtual Compass手動選取分析於赤平投影圓分布圖	FACETS：Kd-tree半自動判釋於赤平投影圓分布圖



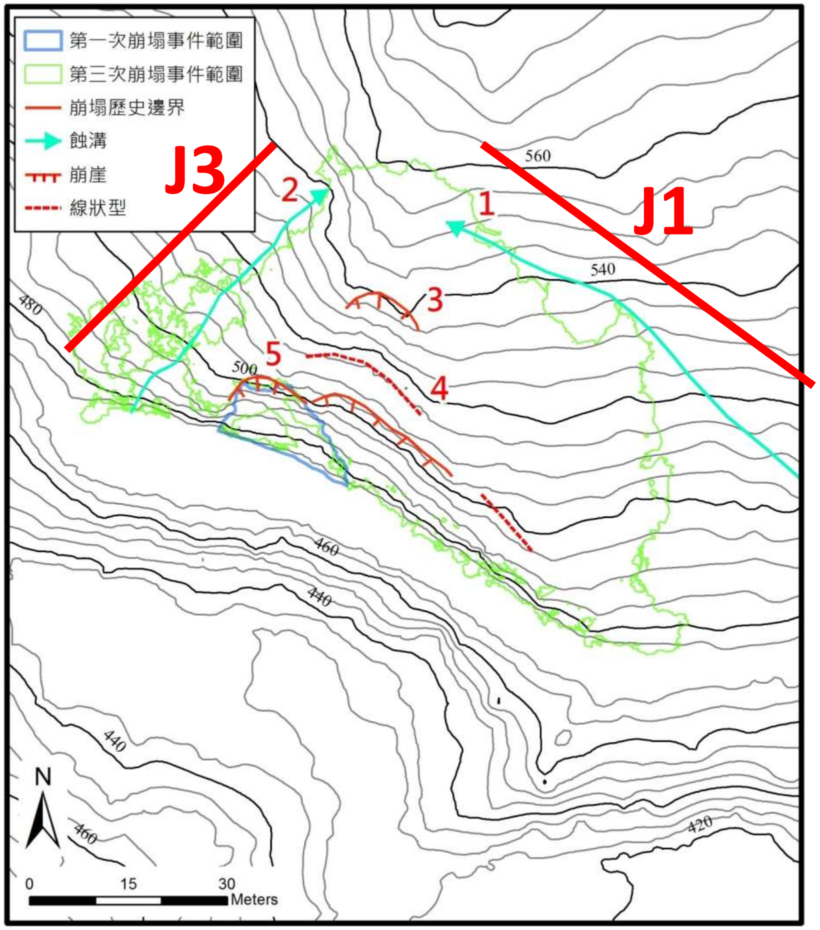
Dip/Dip Dir.(平均)	Name
62/309	B
73/233	J1
40/177	J2
89/311	J3
13/349	J4
42/203	J5



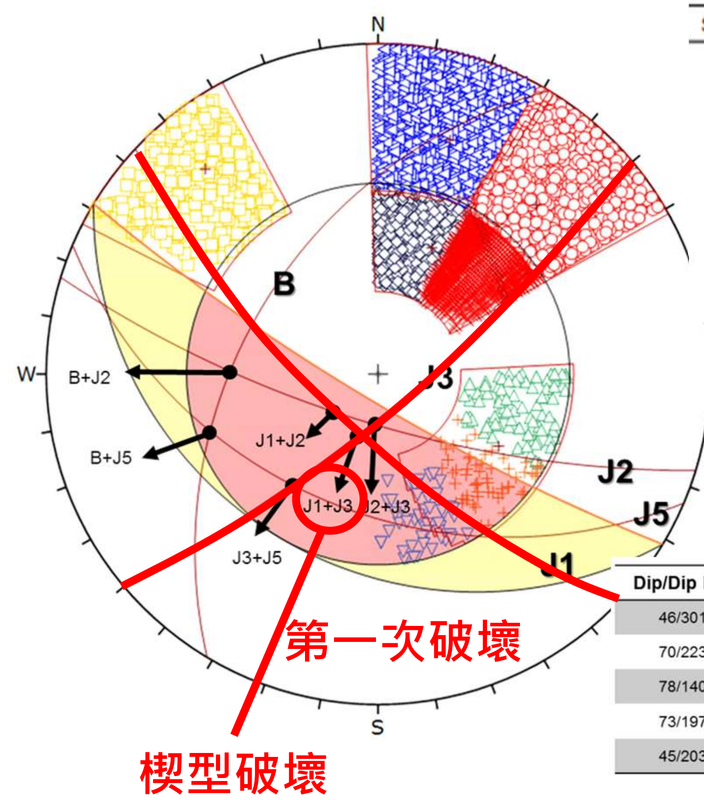
Dip/Dip Dir.	Name
46/301	B
70/223	J1
78/140	J2
73/197	J3
45/203	J5

故除配合**表面積佔比較高之組數**外，亦參考**手動選取**之位態進行位態分群以進行赤平投影分析，以釐清誘發大規模破壞之關鍵**第一次破壞之岩坡運動學機制**，以**了解控制區域岩體不連續面**分布之**關鍵節理組**；配合地形圖與**微地形判釋**可見其**包覆第三次大規模破壞範圍**之蝕溝走向恰如**J1**與**J3**，顯示兩組節理組之重要性。

岩坡破壞運動學機制分析-台7線32K+500



FACETS：Kd-tree半自動判釋於赤平投影圓分布圖

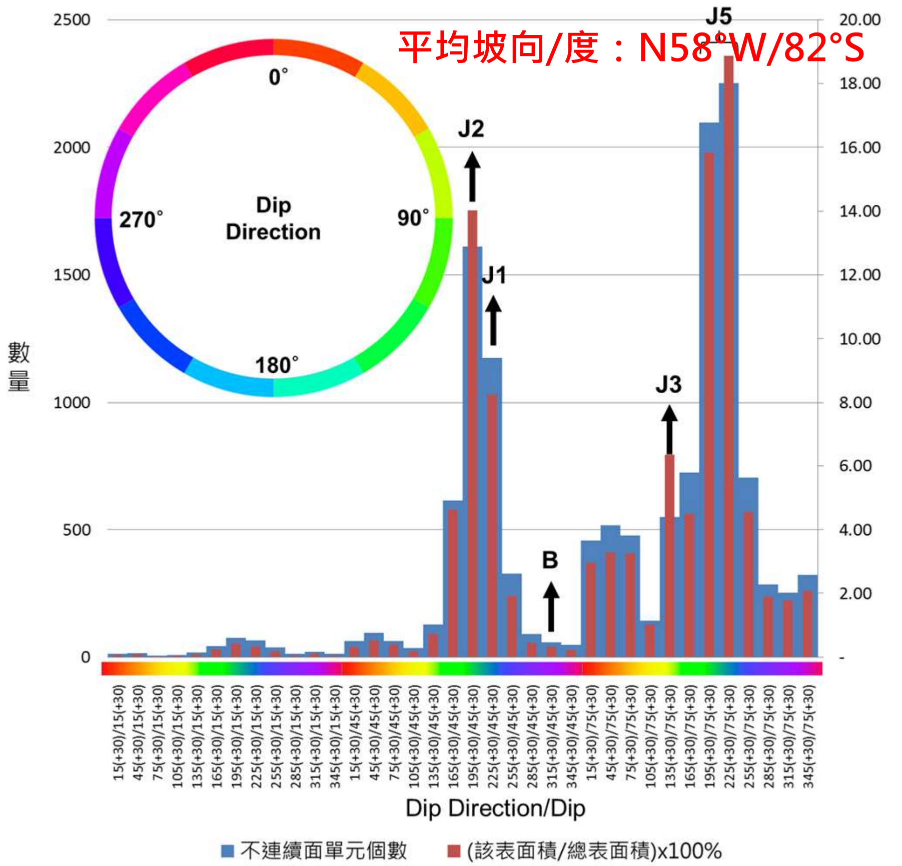


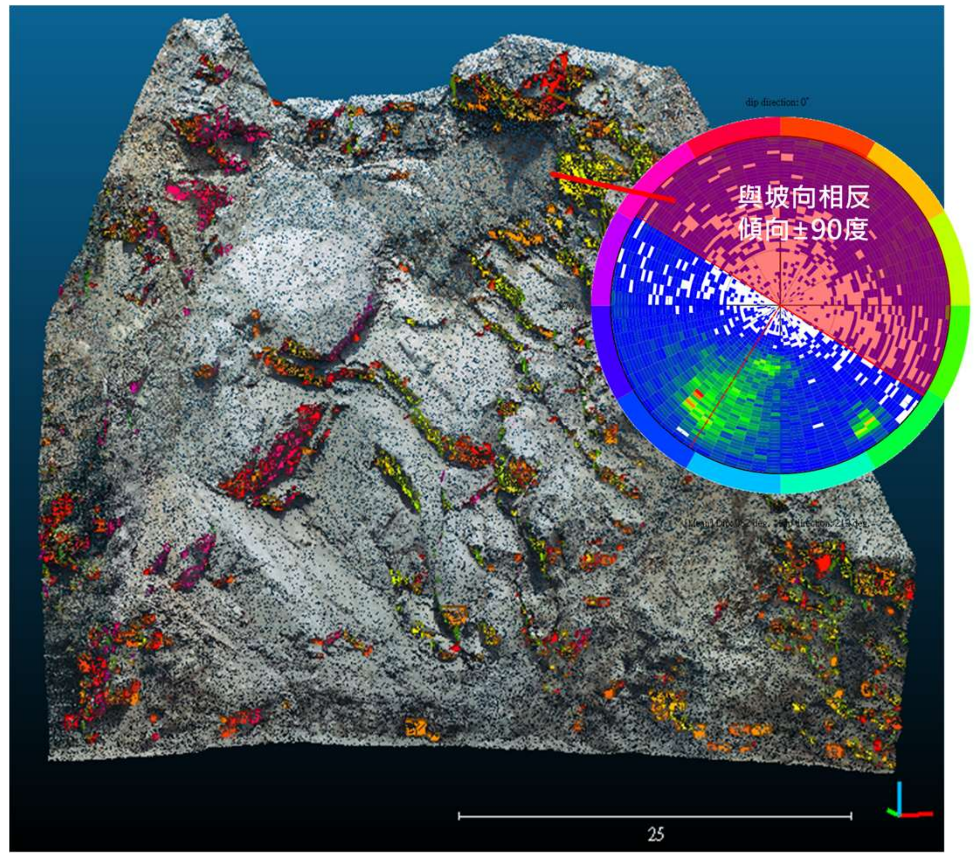
Symbol	Quantity
◇	1612
×	1174
△	90
+	57
▽	49
□	548
◁	2096
○	2252

Dip/Dip Dir.	Name
46/301	B
70/223	J1
78/140	J2
73/197	J3
45/203	J5

故除配合**表面積佔比較高之組數**外，亦參考**手動選取**之位態進行位態分群以進行赤平投影分析，以釐清誘發大規模破壞之關鍵**第一次破壞之岩坡運動學機制**，以**了解控制區域岩體不連續面**分布之**關鍵節理組**；配合地形圖與**微地形判釋**可見其**包覆第三次大規模破壞範圍**之蝕溝走向恰如**J1**與**J3**，顯示兩組節理組之重要性。

倒懸邊坡半自動辨識-台7線32K+500





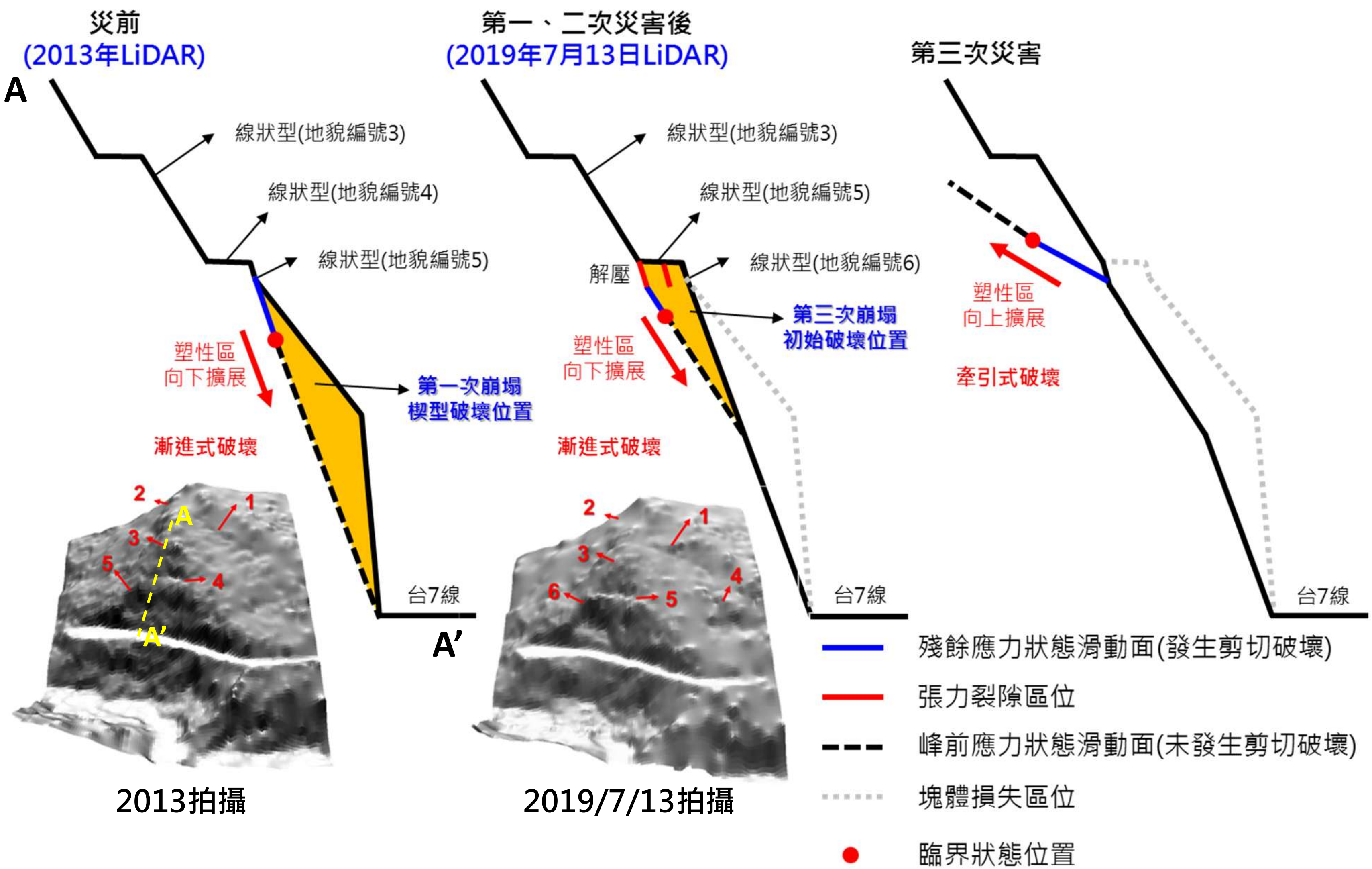
統計後顯示本區位之坡面大多為**N58°W/82°S(約略與J5相同)**，呈**高角度往南傾**之坡向狀態(呈藍色之顯示狀況)，配合**不連續面位態分布配合個數**與**所佔分析總面積**之**比例統計分布圖**，瞭解到部分不連續面之位態佔坡面比例甚低，可能為誤差或是雜訊之現象，配合與整體坡向相反區位即可將９成以上倒懸區位找出。

邊坡坡壞機制分析-台7線32K+500

台7線32K+500第三次崩塌事件初始位置與第一次、第三次事件關係圖

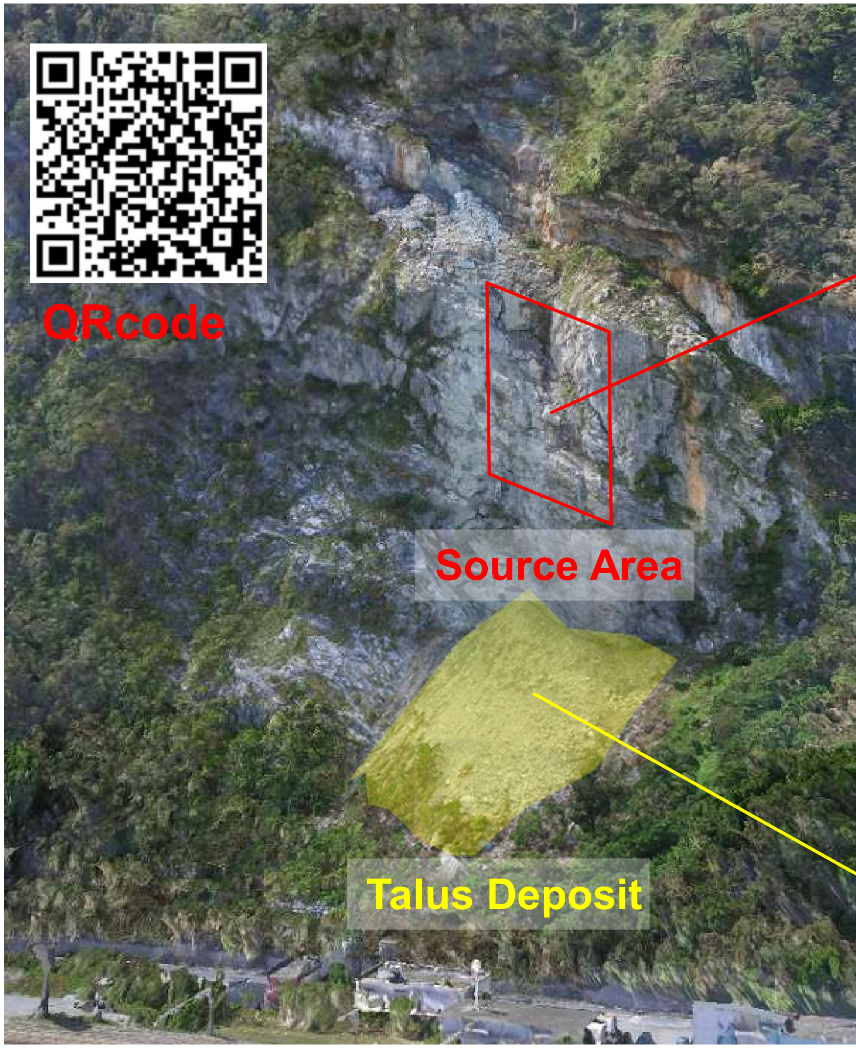
2019年7月28日現場工程人員拍攝之影片，可見其**第三次大範圍崩塌**之**破壞初始位置**，坐落於**微地形地貌線狀型**與**崩崖**之間，印證**第一次崩塌**之塊體損失後，造成**發生區上方**之坡體已失去支撐，並已**解壓**使既有**線狀型破壞加據**，除**往東側延伸**之情況外，可能也因解壓引致**張力裂縫發育**，故於2019年7月13日之陰影圖上之線型有更明顯之顯現，造成第三次邊坡之**大規模牽引式破壞**(retrogressive failure)。

邊坡坡壞機制分析-台7線32K+500

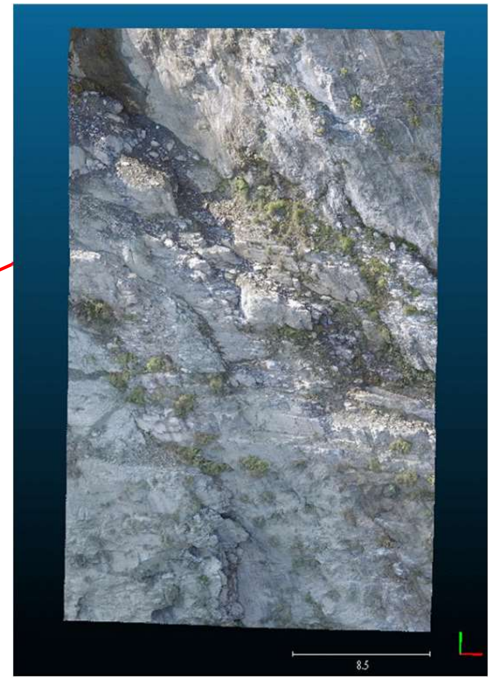


地貌狀況與不連續面辨識-漢本

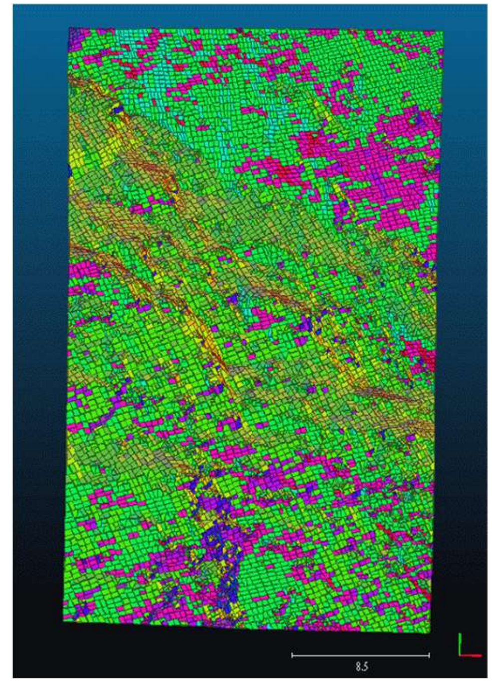
Airscape Image



The View of 3D-Model



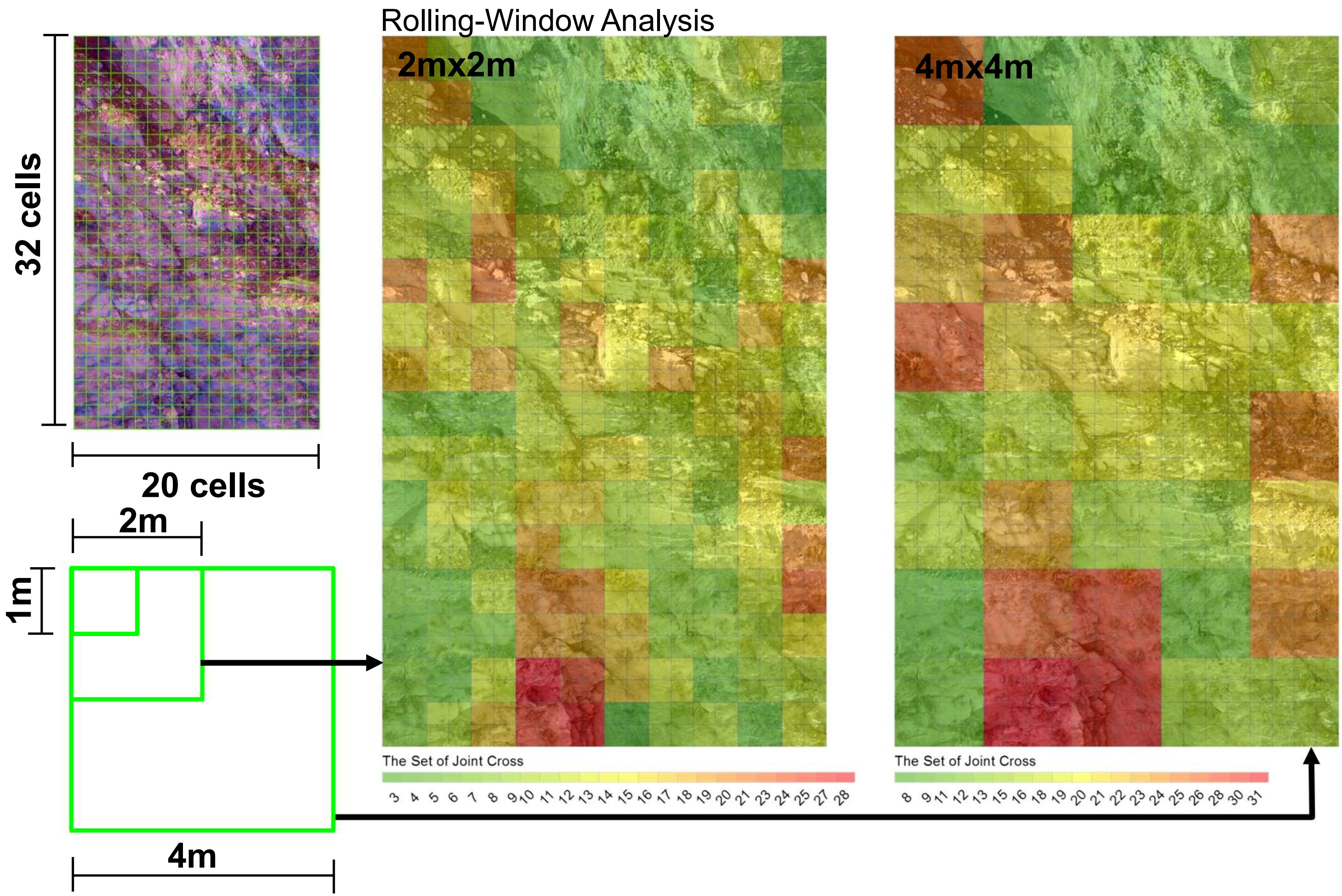
The View of Orientation Unit Model



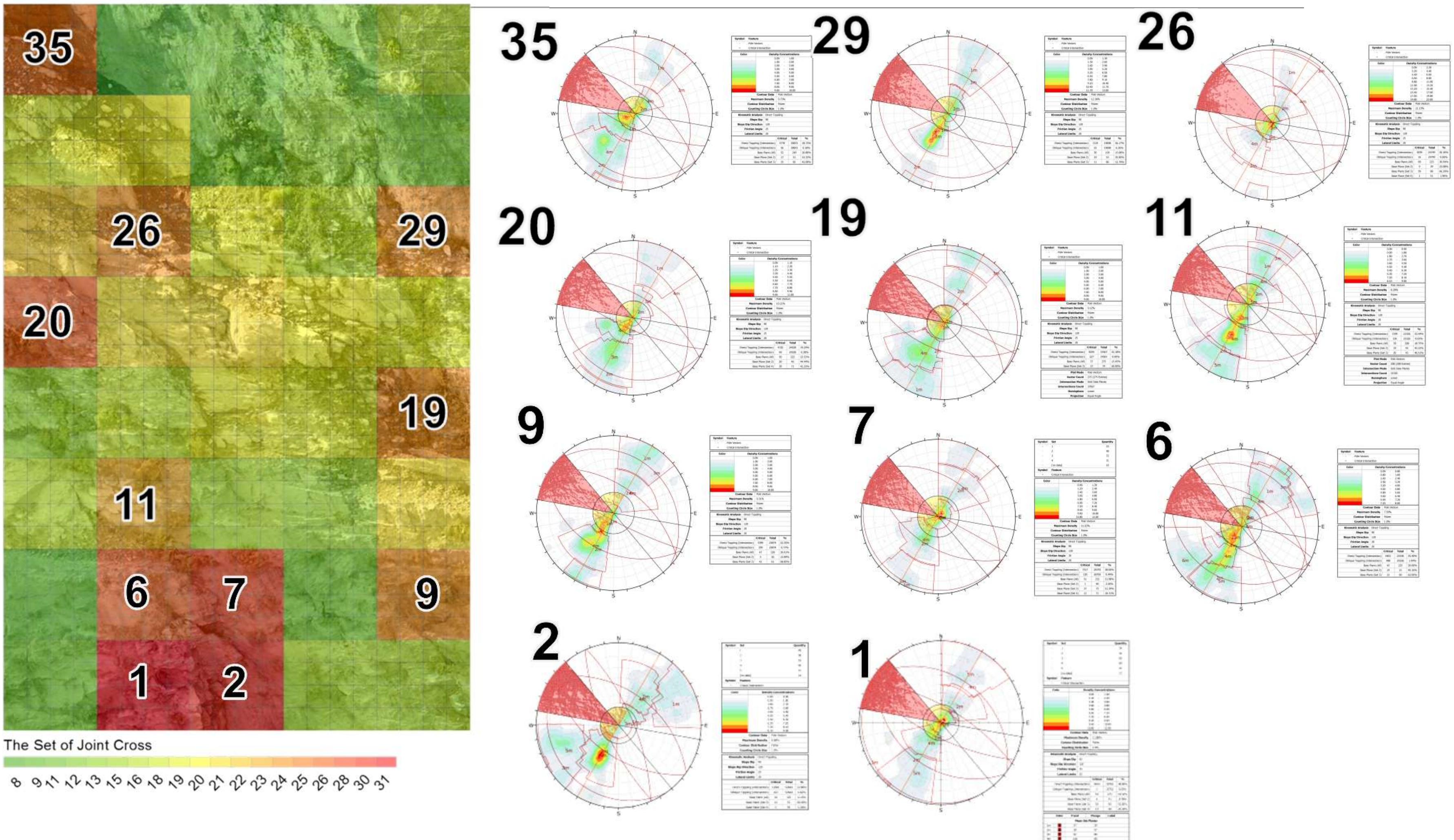
The Shape of Boulder

應用地質技師公會
財團法人中興工程顧問社
SINOTECH ENGINEERING CONSULTANTS, INC.

The Analysis of Scale and Discontinuities Distribution



Rolling-Window Analysis and Kinematic Admissibility

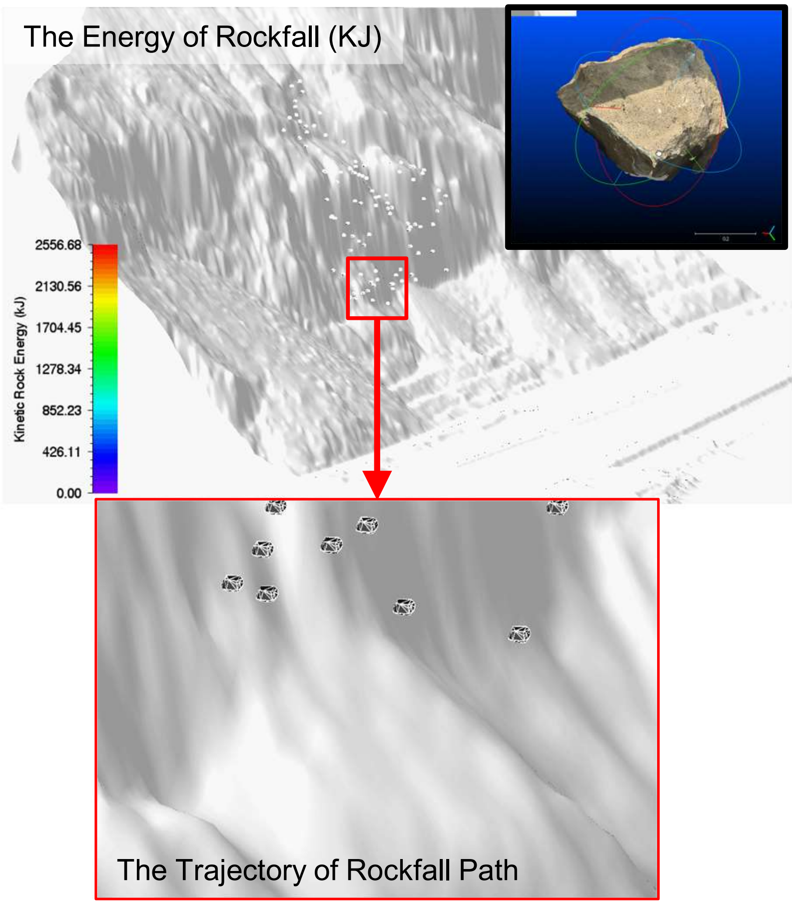


- Extract the area of plane intersected by discontinuities planes more than the 20 sets of the window analysis size 4 by 4 had 11 zones
- The result shows that the orientation of discontinuities planes are similar, which indicate direct toppling is the main failure type.

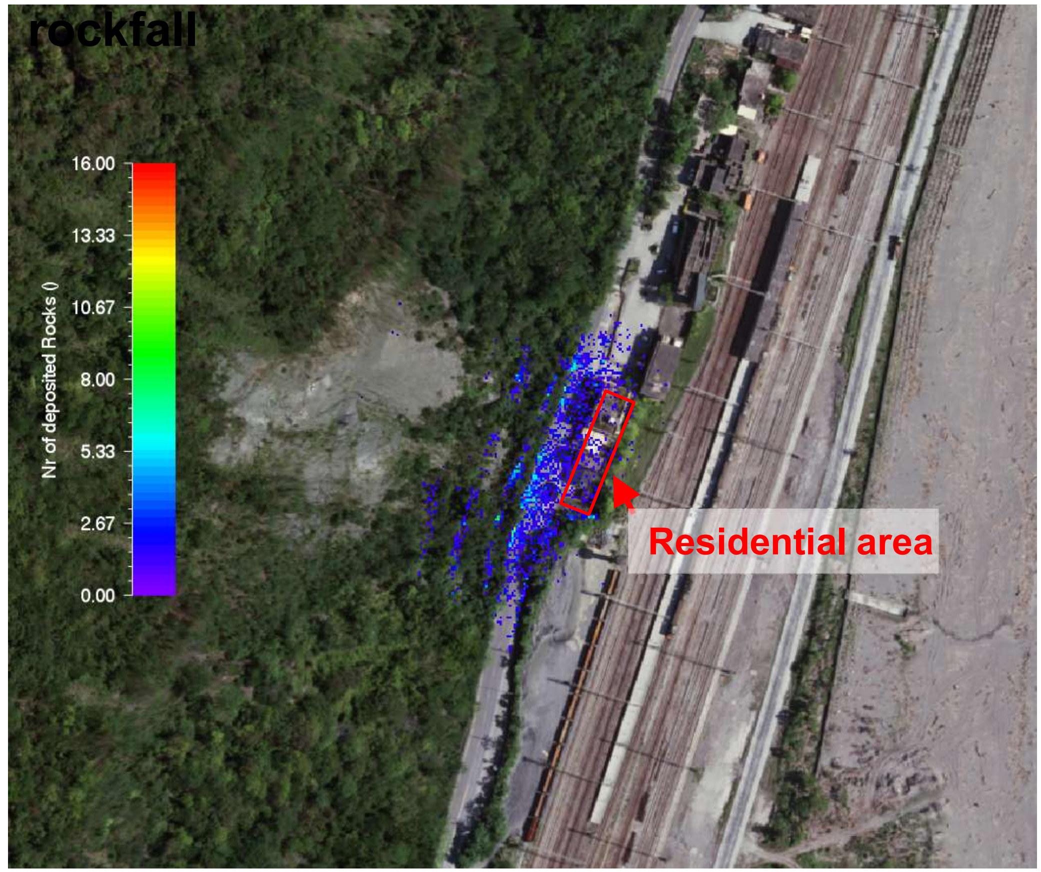
Application of Point Cloud for Simulation

RAMMS
rapid mass movements

The shape build by UAV photogrammetry



The Simulation and Distribution Result of rockfall



- Input the source on the critical region of direct toppling, and build the shape with the UAV photogrammetry.
- The RAMMS::ROCKFALL was used to simulate ockfall, the mode was developed by WLS in Switzerland.

結論

- The UAV image-based point cloud analysis method in this study will not be limited by steep terrain and will increase efficiency of outcrop measurement at rock slope

- The rock slope failure mechanism results were clearly shown by UAV image-based point cloud with Rocscience Dips software, and the rock slope weak surface position and hanging block could be highlight by the analysis.

- Using the model constructed by point could provide more REAL situation for rockfall numerical simulation.

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Sinotech Disaster Prevention Technology Research Center

https://dptrc.sinotech.org.tw/index_en.php

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THANKS FOR YOUR ATTENTION