國立中央大學

National Central University






離心模型試驗在邊坡破壞行為模擬之研究



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107年6月12日

行政院農業委員會水土保持局

Soil and Water Conservation Bureau,
Council of Agriculture, Executive Yuan.

大綱

1. 離心模型試驗簡介
   - 1.1 離心模型試驗原理
   - 1.2 離心模型試驗設備
   - 1.3 過去研究成果
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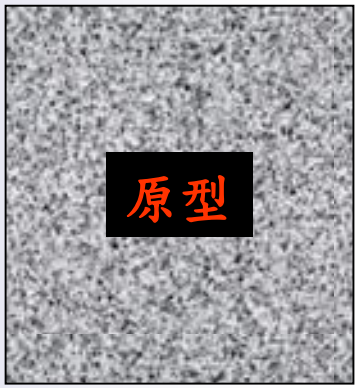
4. 小結

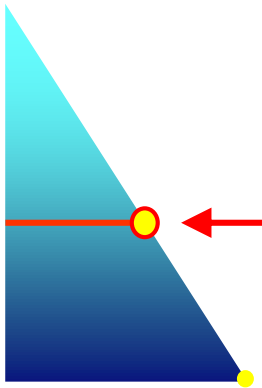
1. 離心模型試驗簡介

離心模型物理模擬

現場

100公尺土層
或水深





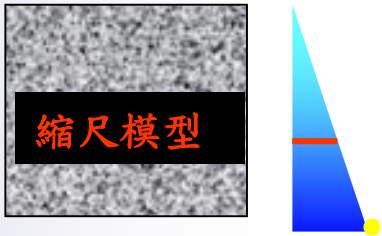
相對應點之應力-應變情況相同

$\gamma \cdot H = \rho g H$

小模型於1 g 狀態試驗

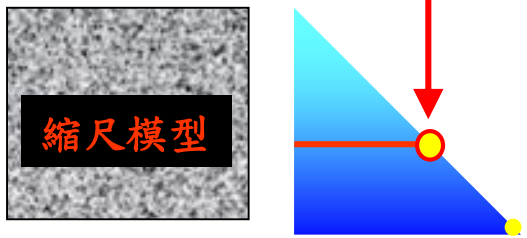
小模型置於離心模型試驗**100 g**離心力場

1公尺土壤
或水工模型



$$\gamma \cdot \frac{H}{N} = \rho g \frac{H}{N}$$

1公尺土壤
或水工模型



$$\gamma \cdot N \cdot \frac{H}{N} = \rho g H$$

各項物理量之尺度轉換因子

Scaling factors for centrifuge modeling test (model/prototype)

Physical properties	Scaling factor
Length	$1/N$
Area	$1/N^2$
Volume	$1/N^3$
Velocity	1
Acceleration	N
Mass	$1/N^3$
Force	$1/N^2$
Energy	$1/N^3$
Stress	1
Strain	1
Mass density	1
Energy density	1
Time (dynamic)	1/N
Time (diffusion)	$1/N^2$
Frequency	N

➡ N表示離心力場與地球重力場的比值

➡ 基本條件

➡ 相同材料與相同初始條件

- 邊界效應
- 顆粒尺寸效應
- 重力場分布問題

NCU大型力學實驗館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中壢市五權里一鄰38號
Department of Civil Engineering
Chungli, Taiwan 32054, Republic of China
TEL：886-3-4255239 FAX：886-3-4252960
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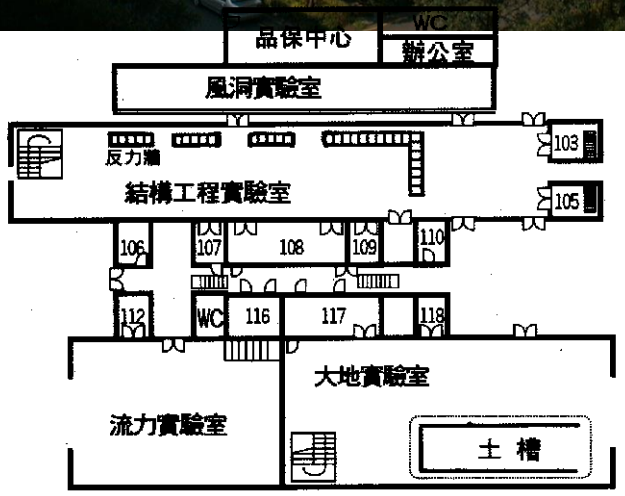
品保中心
WC
辦公室
風洞實驗室
反力牆
結構工程實驗室
103
105
106
107
108
109
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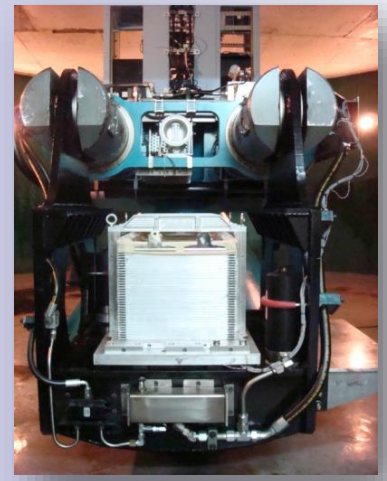
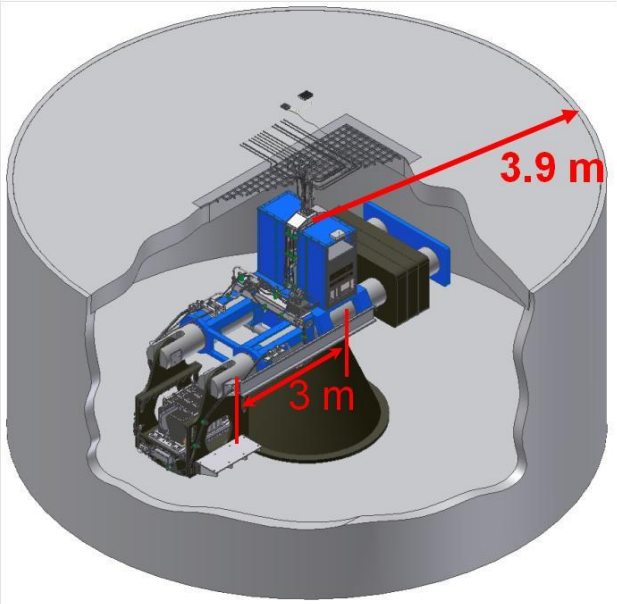
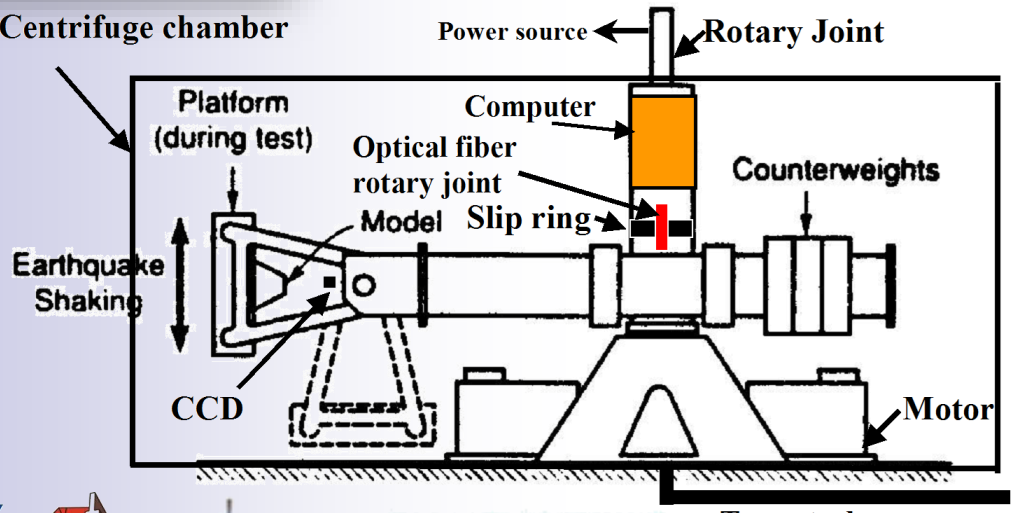
WC
116
117
118
大地實驗室
流力實驗室
土 槽

NCU地工離心機



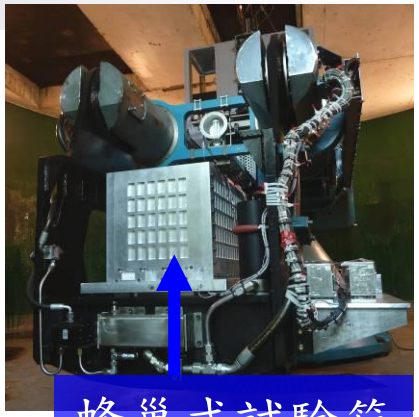




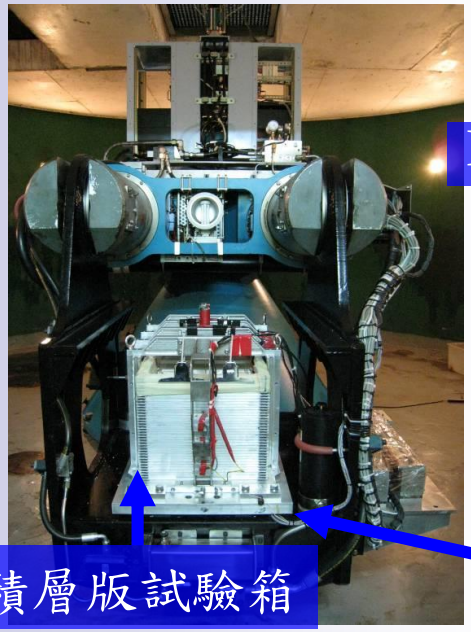
Nominal radius	3 m
Max. Payload (Static Test)	1000kg
Capacity	100 g-ton

NCU離心振動台

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



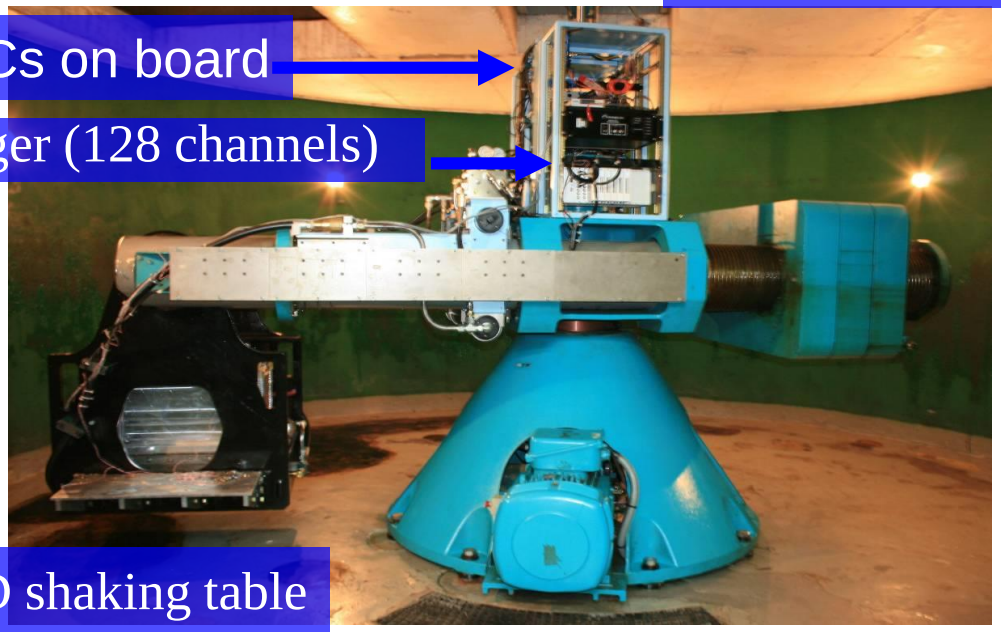
蜂巢式試驗箱



積層版試驗箱

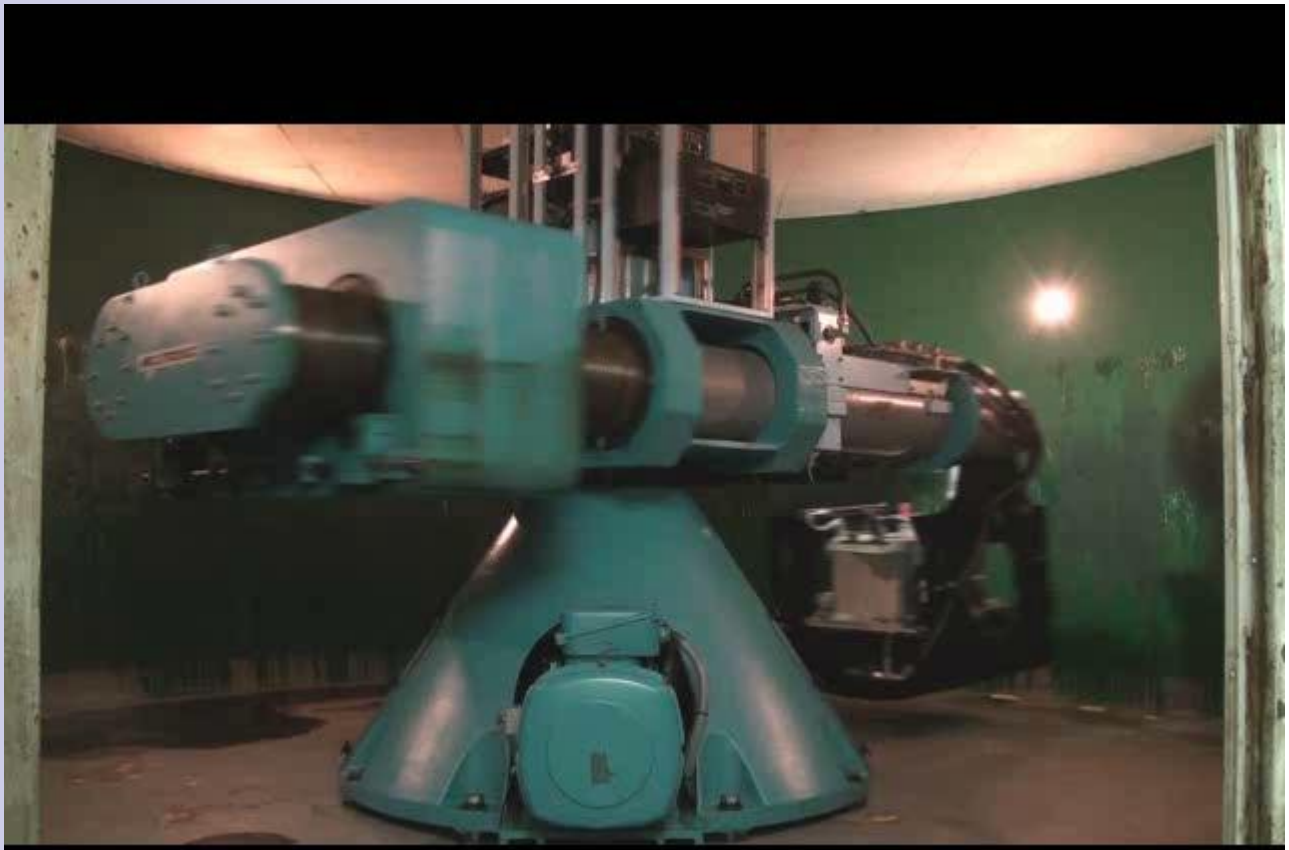
2 PCs on board

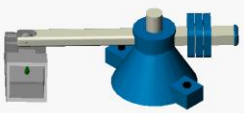
Data logger (128 channels)



1-D shaking table

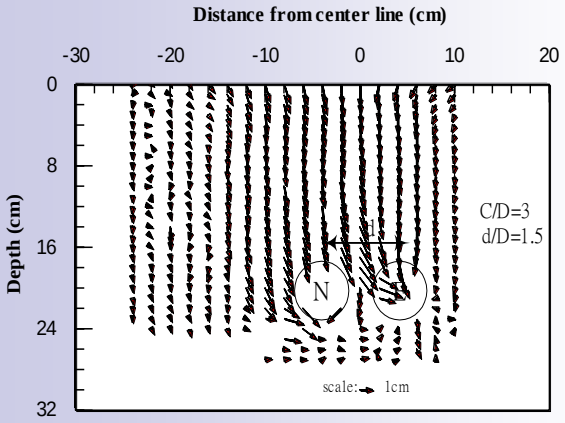
NCU地工離心機

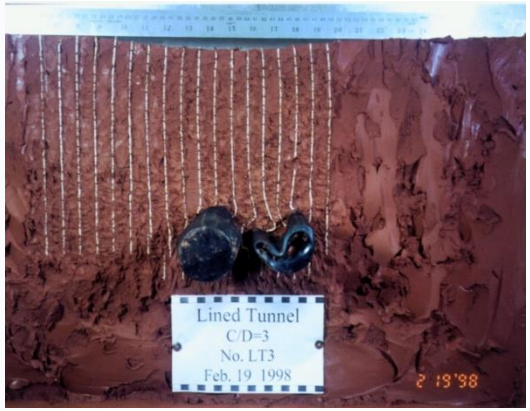


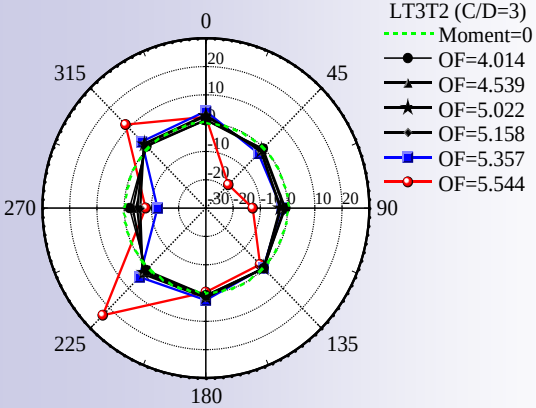


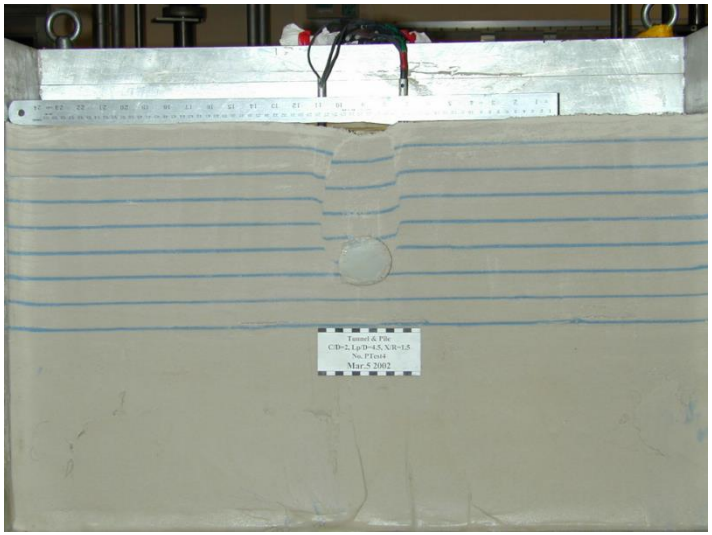
優點：快速、經濟、可探討破壞行為與改善對策的有效性

不同地盤與埋置條件隧道破壞行為

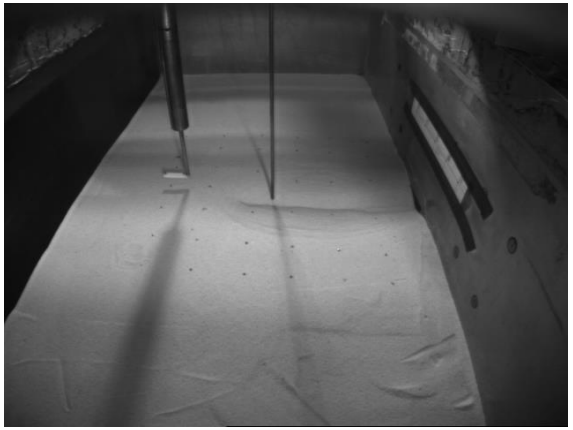


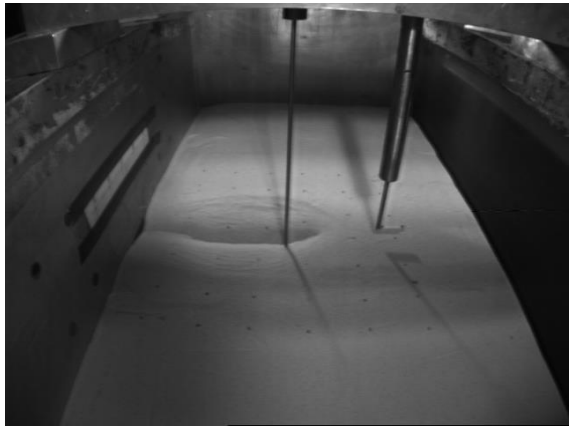


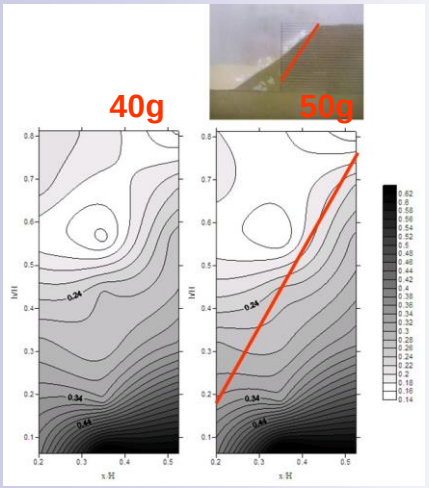


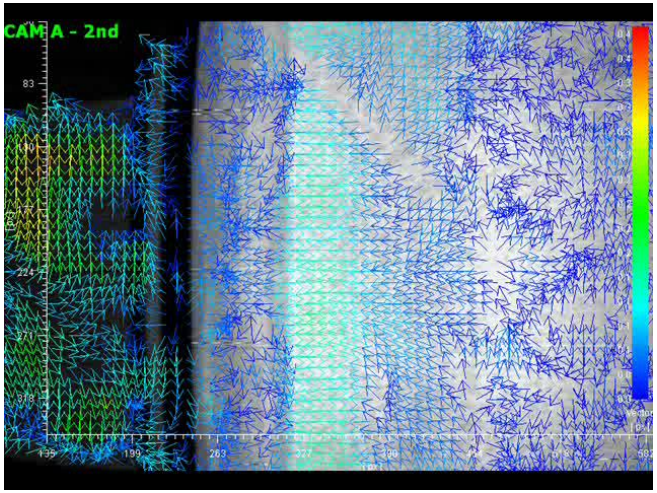


擋土牆變形破壞與土石壩滲流破壞

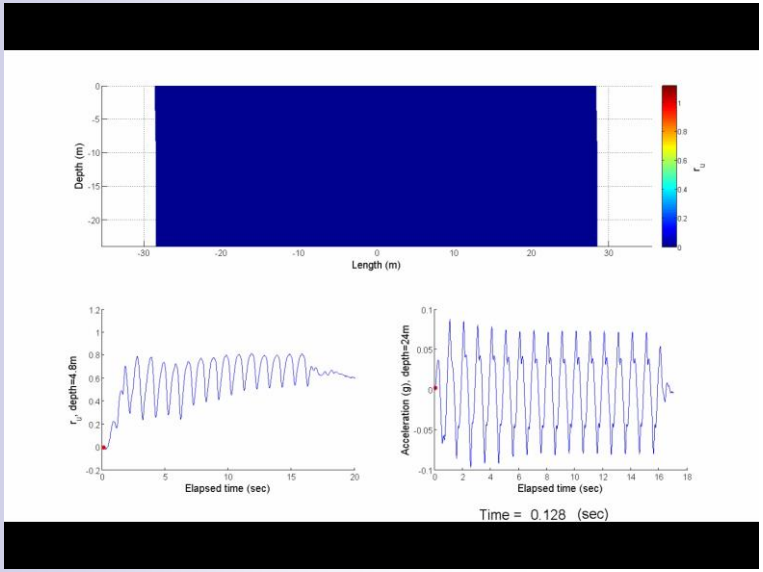


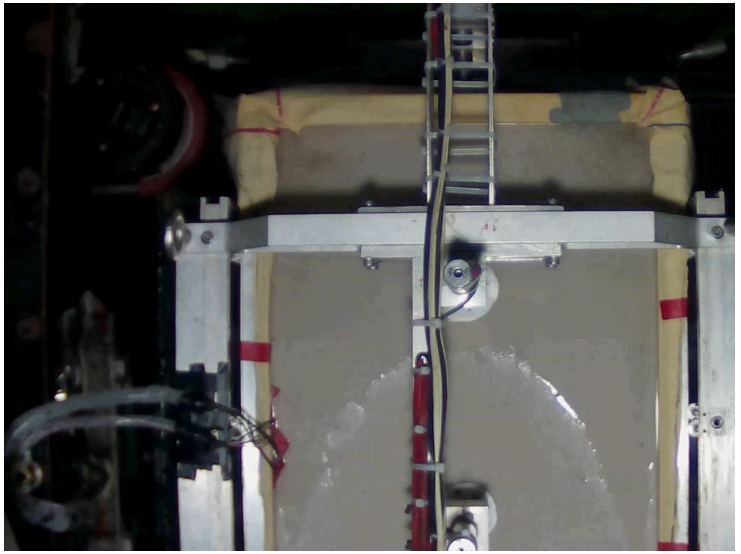


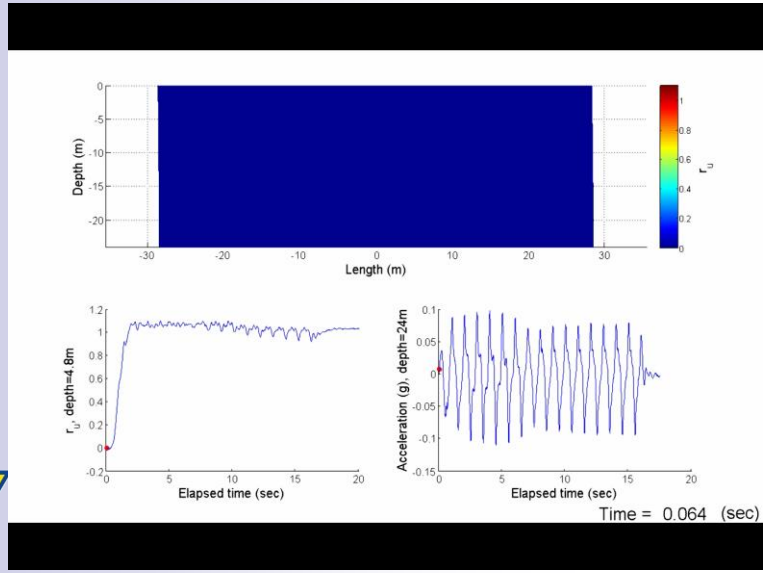


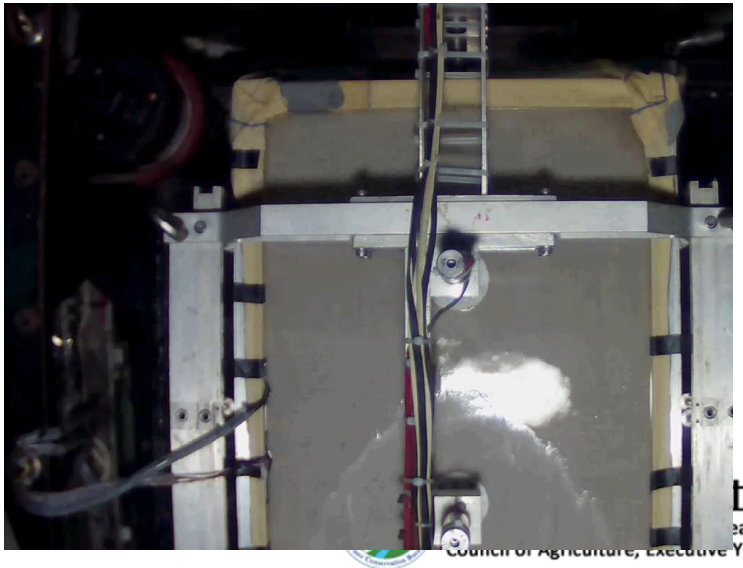


土壤液化引致相關破壞行為

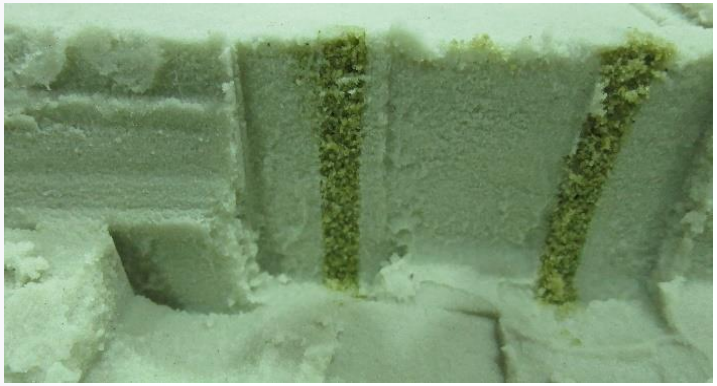


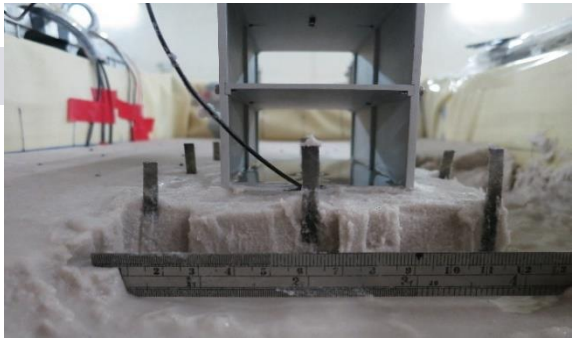


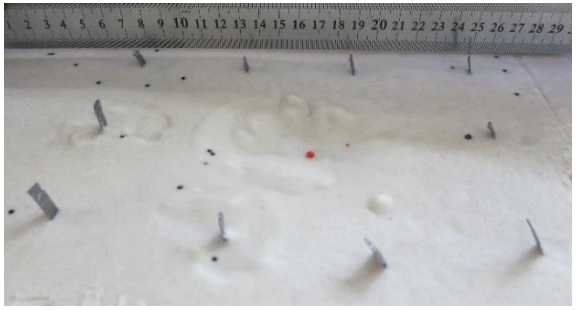


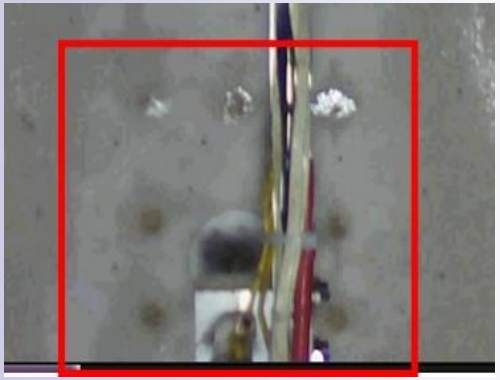


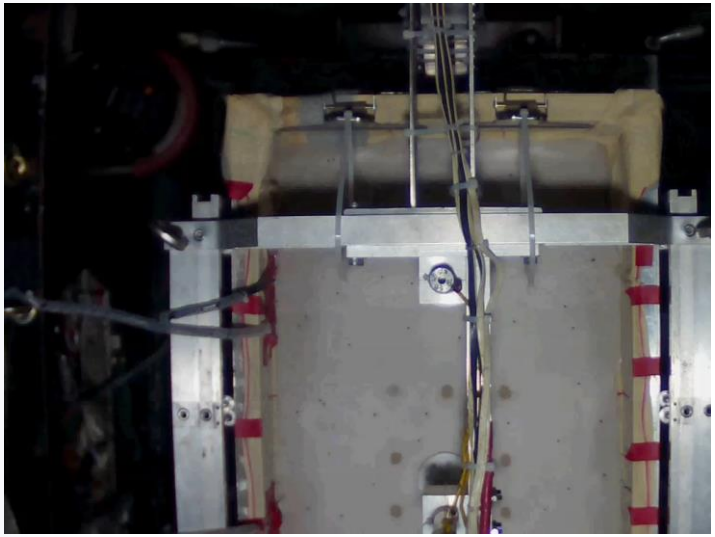
垂直排水方法抑制土壤液化之有效性

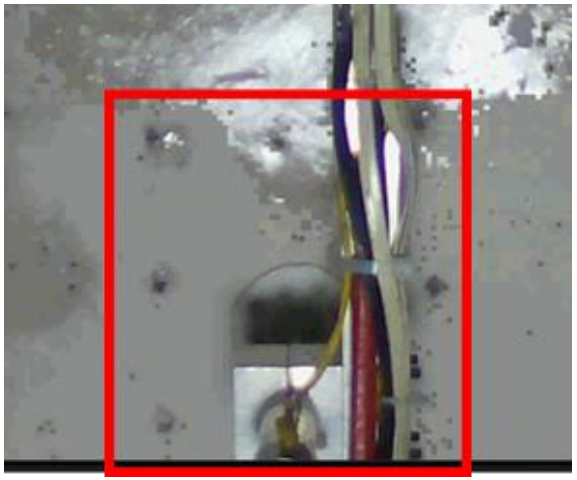




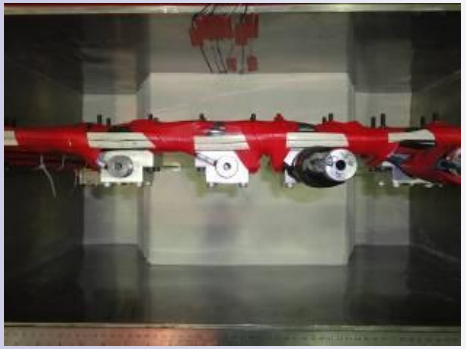


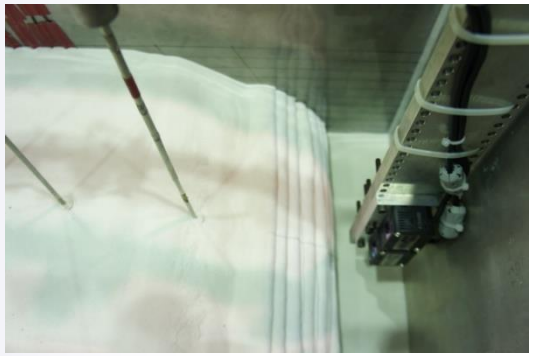


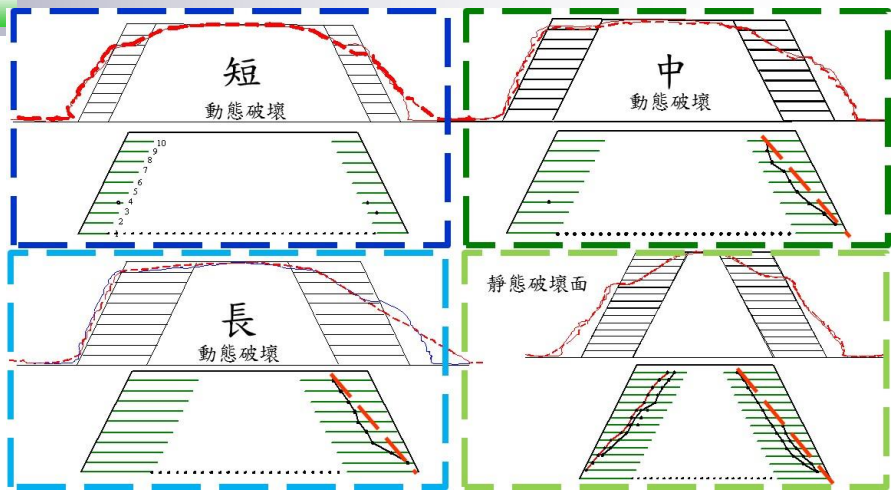




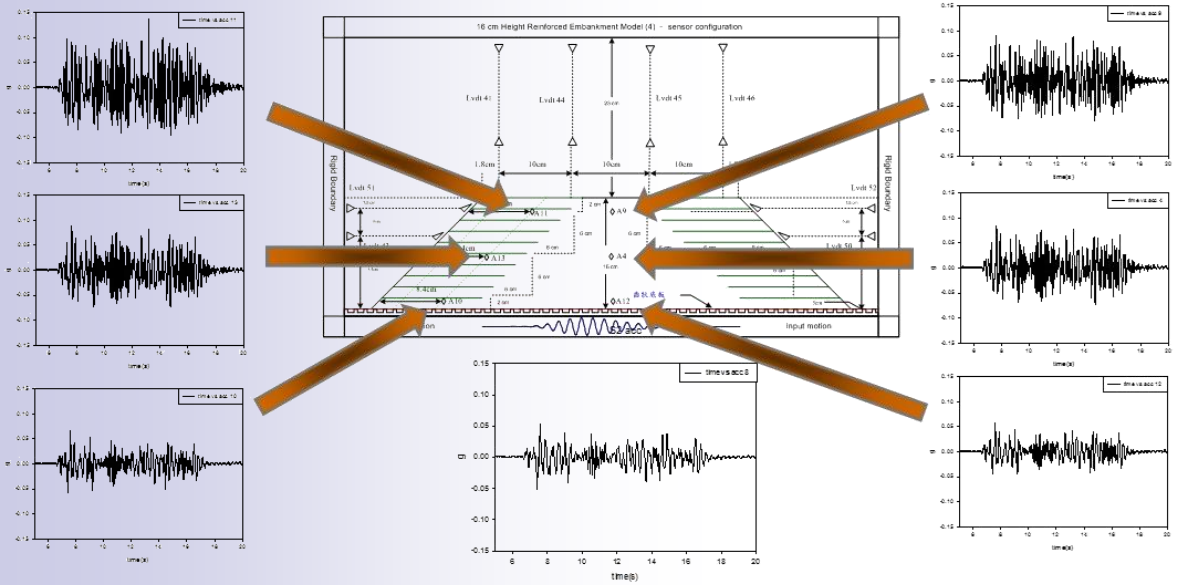
加勁土堤離心模型振動台試驗

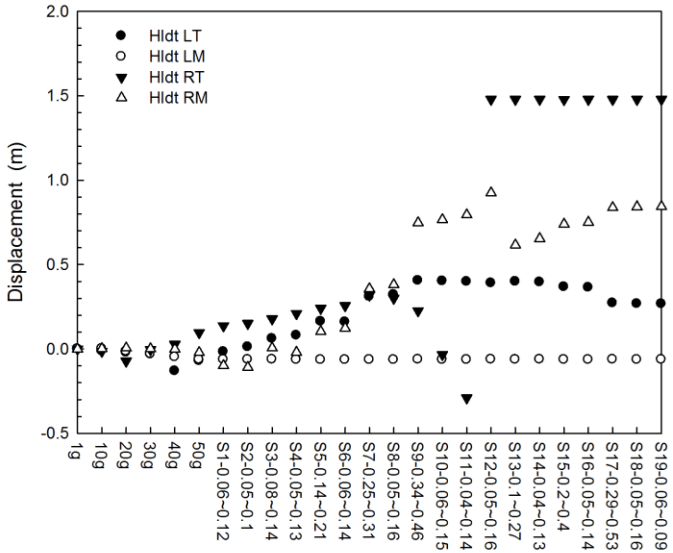






White noise

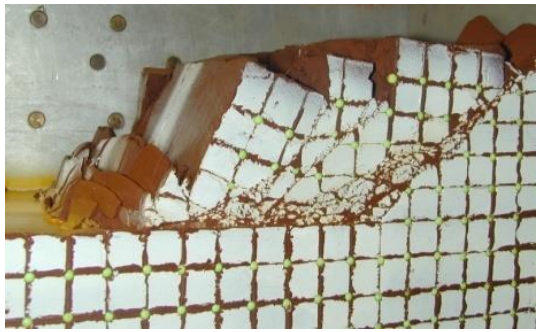


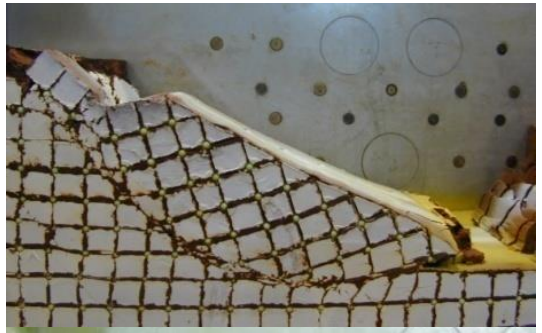


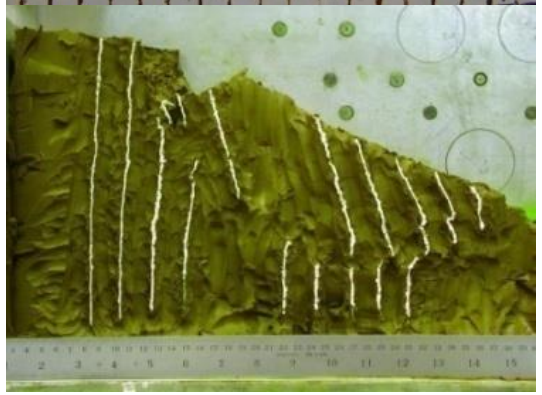
離岸風機基礎受反覆側向力與土壤液化時之行為

2. 邊坡破壞行為

2.1 邊坡破壞行為-重力因素



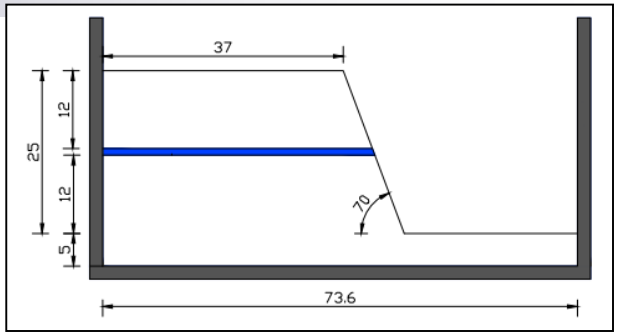


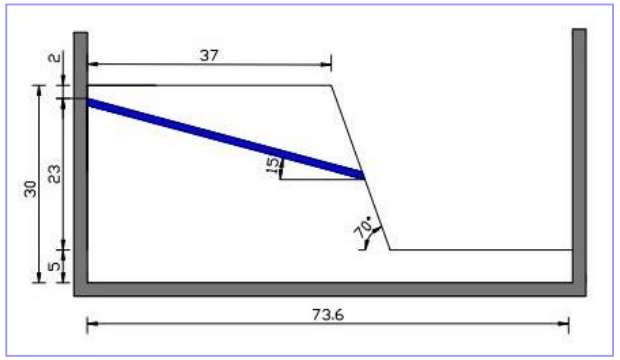


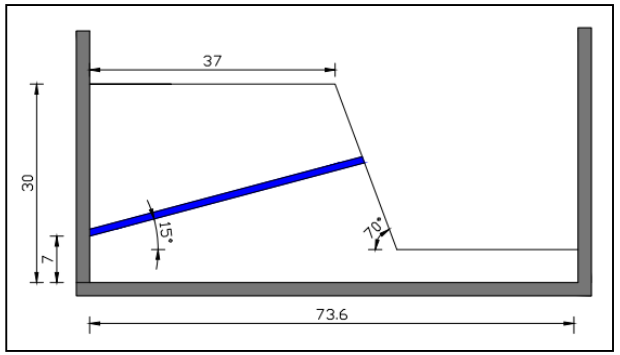
2.1 邊坡破壞行為-重力因素

模型尺寸：
基礎土壤厚：50 mm
坡高：250 mm
坡角：70 度

夯實度：90 %
含水量：10-12%
礫石層相對密度：60 %





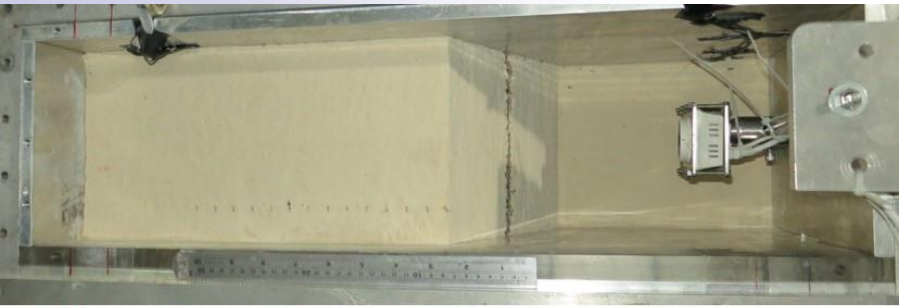


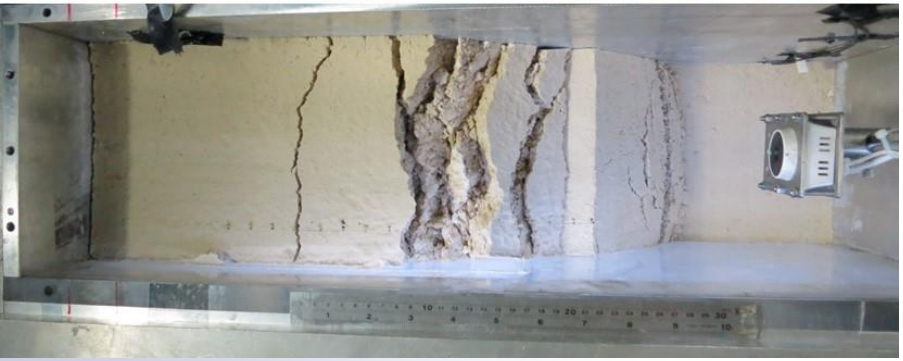
Model	礫石薄層	單位重 (kN/m^3)	含水量 (%)	試驗條件
M1	水平	14.61	12	Gravity
M2	15度傾斜向下	17.19	10	Gravity
M3	15度傾斜向上	17.19	10	Gravity
M4	水平	17.19	10	Gravity
M5	15度傾斜向下	17.19	10	Earthquake

2.1 邊坡破壞行為-重力因素

Model M1

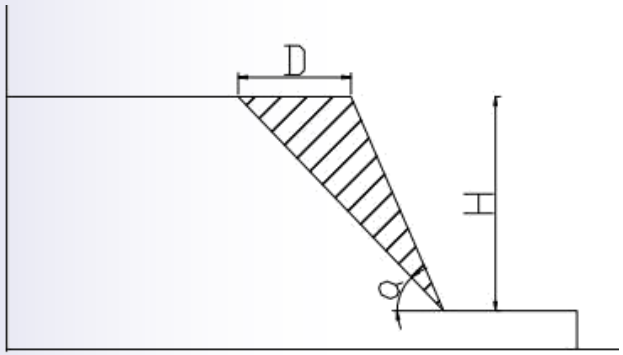
Width	0.01 H
Depth	0.128 H
Distance	0.792 H

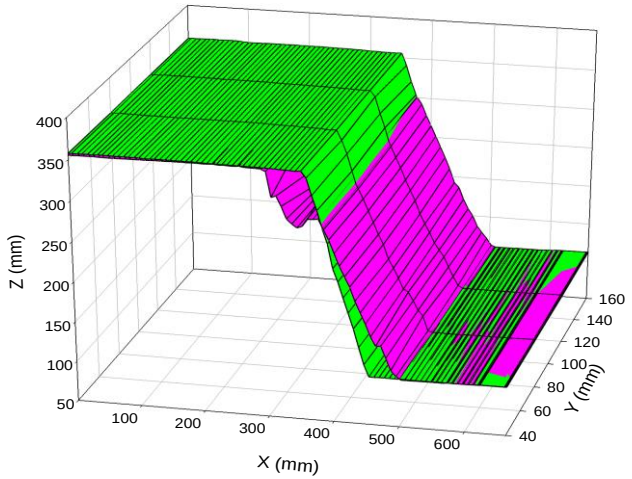




2.1 邊坡破壞行為-重力因素

Model	M1	M2	M3	M4
Failure g level (g)	15	35	40	55
Prototype height (m)	3.75	8.75	10	13.75
D (m)	1.6	2.94	3.44	2.99
D/H	0.43	0.33	0.34	0.21
α (Degrees)	51	54	54	59
c (kN/m^2)	5.82	13.2	13.2	13.2
γ (kN/m^3)	14.61	17.19	17.19	17.19
c/γH	0.1	0.08	0.07	0.05

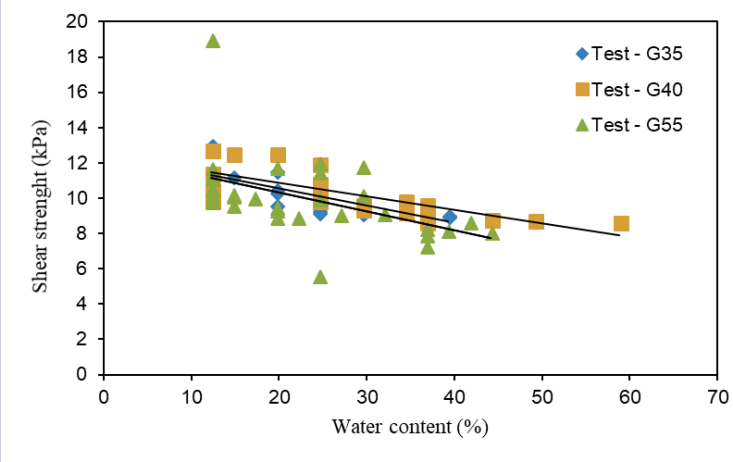


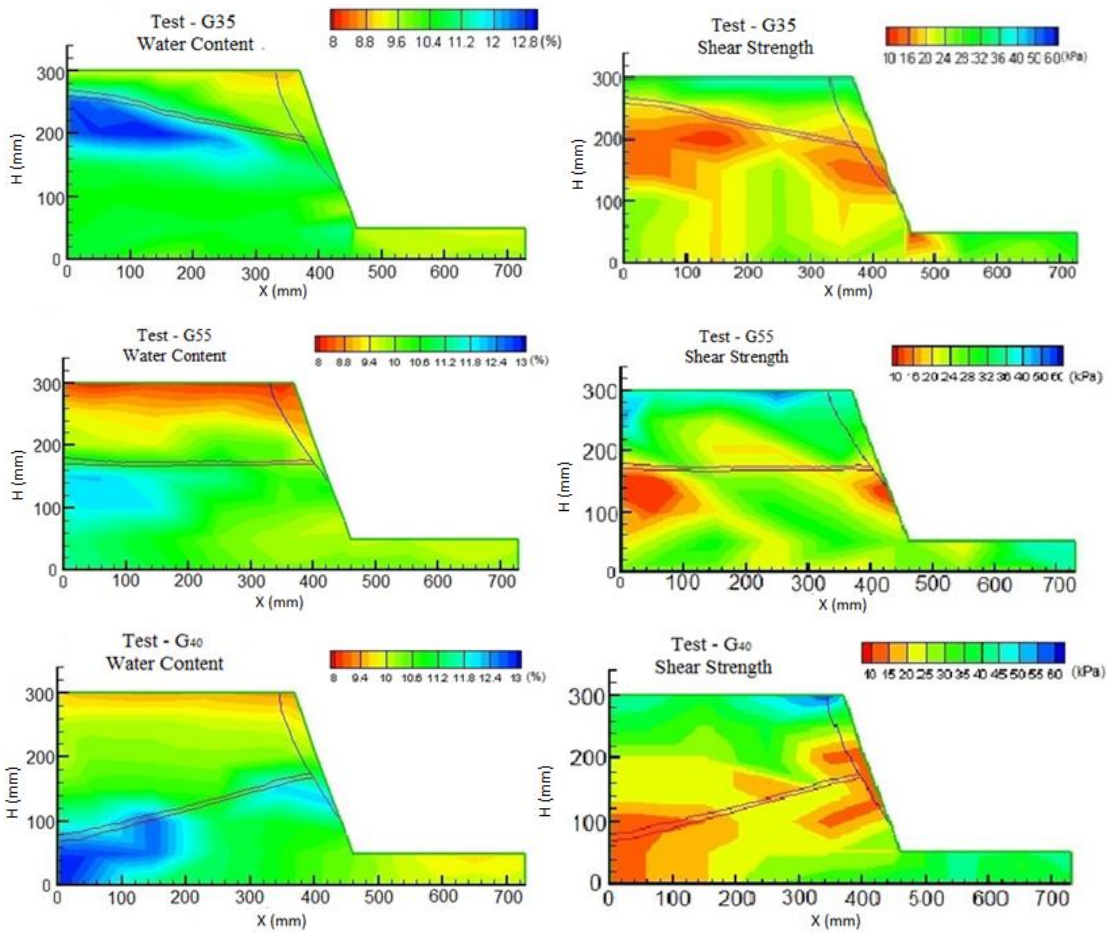


2.1 邊坡破壞行為-重力因素

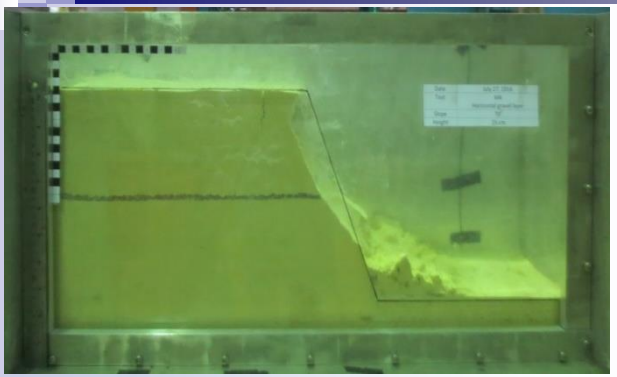
含水量與土壤強度關係

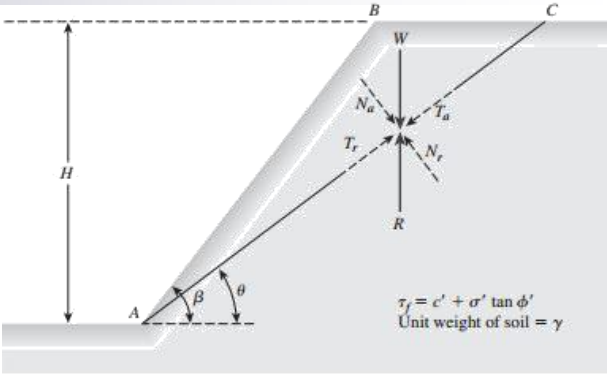
土壤孔隙的水因重力場與
內部薄透水層移動





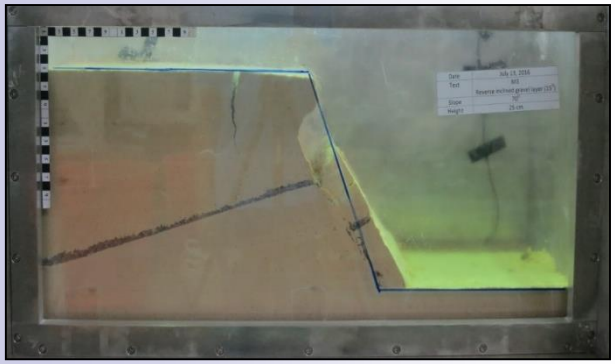
2.1 邊坡破壞行為-重力因素

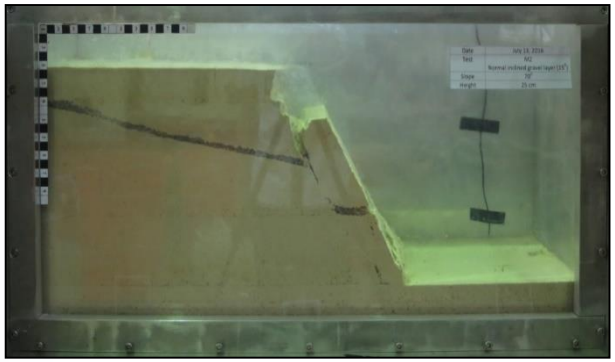


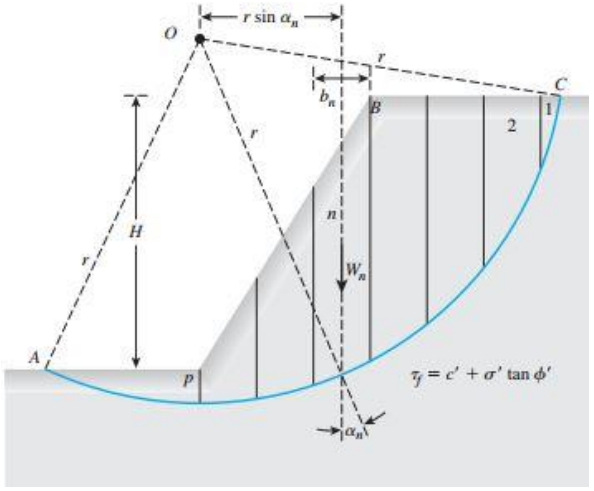


邊坡剖面

邊坡前視

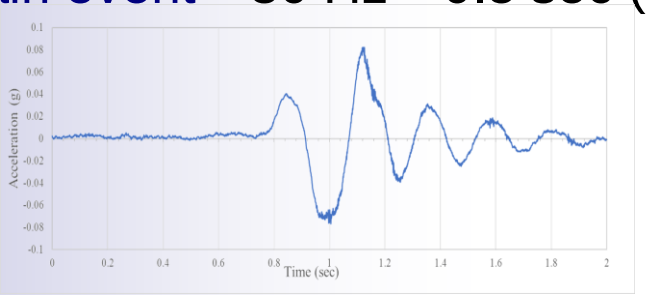


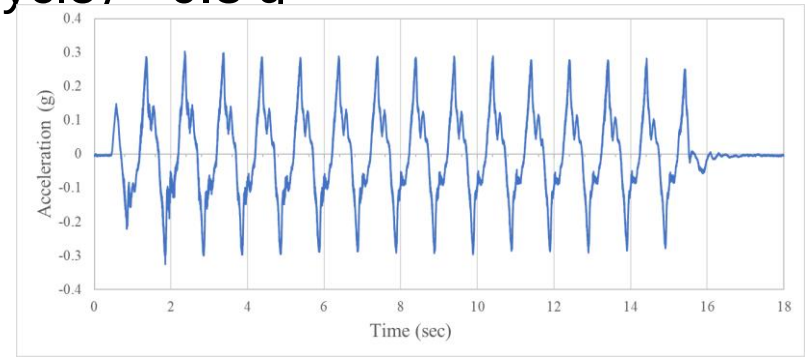




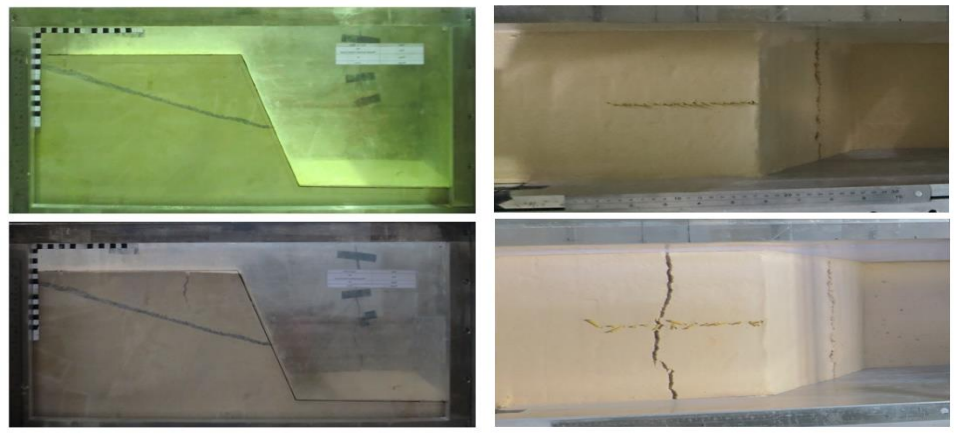
2.2 邊坡破壞行為-地震力因素

- Pre-shaking：90 Hz、0.0111sec (1 cycle)、0.02 g
- Main event：30 Hz、0.5 sec (15 cycle)、0.3 g

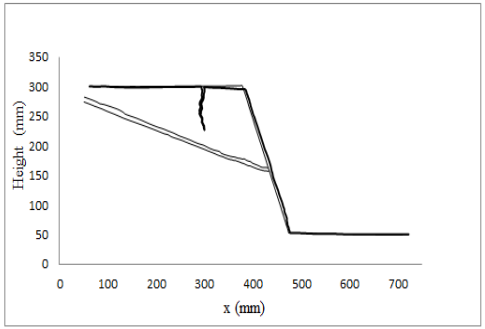


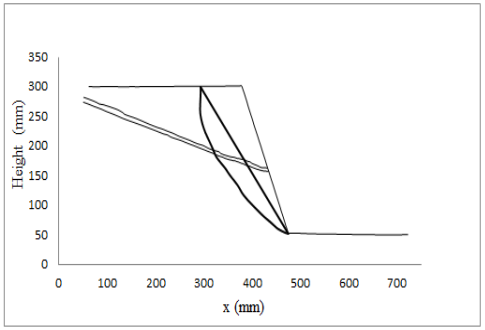


- Height: 7.5 m
- Tension crack： 寬0.009 H、深 0.030 H、距離坡頂 0.352 H

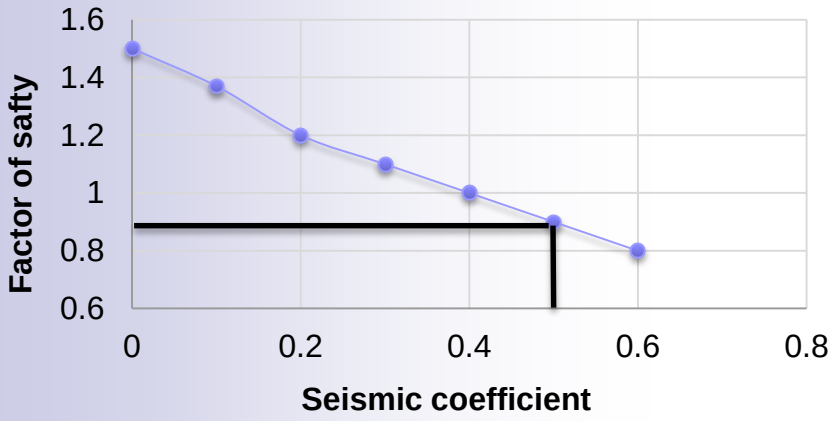


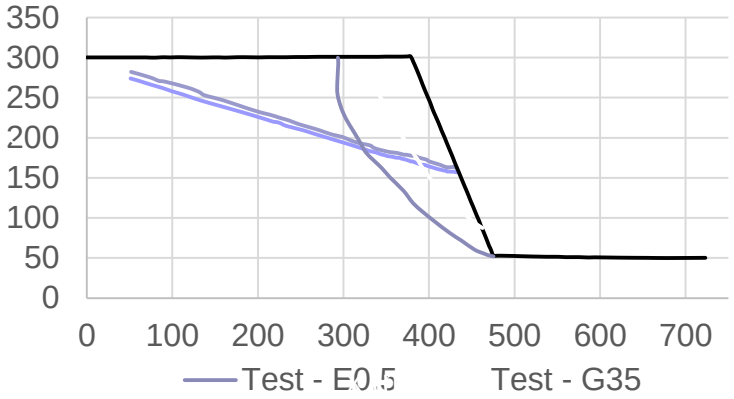
2.2 邊坡破壞行為-地震力因素



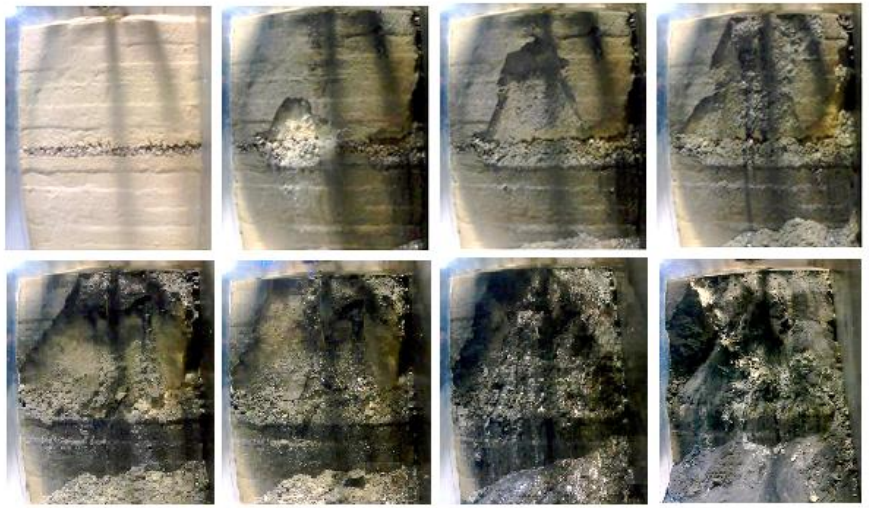


$$F_S = \frac{\sum cL + \sum(W\cos\alpha - kW\sin\alpha)\tan\varphi}{\sum(W\sin\alpha + kW\sin\alpha)} = 0.9$$





2.3 邊坡破壞行為-降雨因素

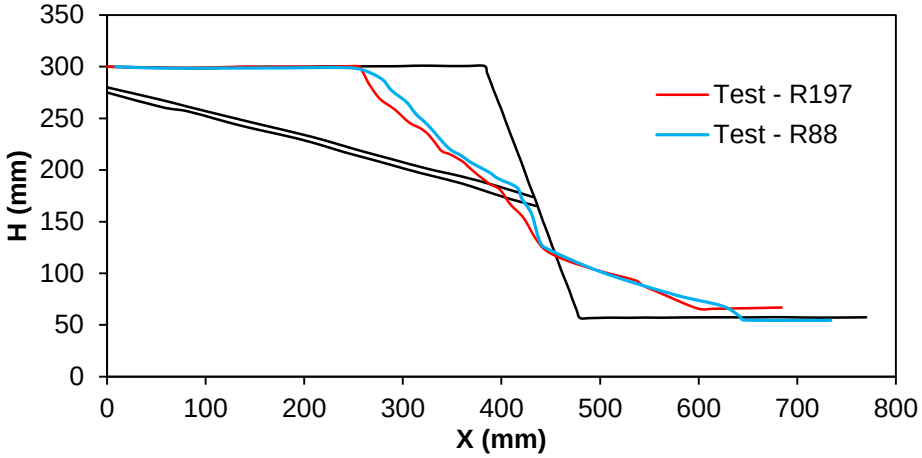


Rainfall	Model	Prototype
Intensity	1	1
Duration	1	N
Total rainfall	1	N

Rainfall condition	Test – R197	Test – R88
Intensity (mm/h)	197	88
Duration (h)	3.3	7.4
Total rainfall (mm)	651	651
Effective distance, D (m)	0.50 H	

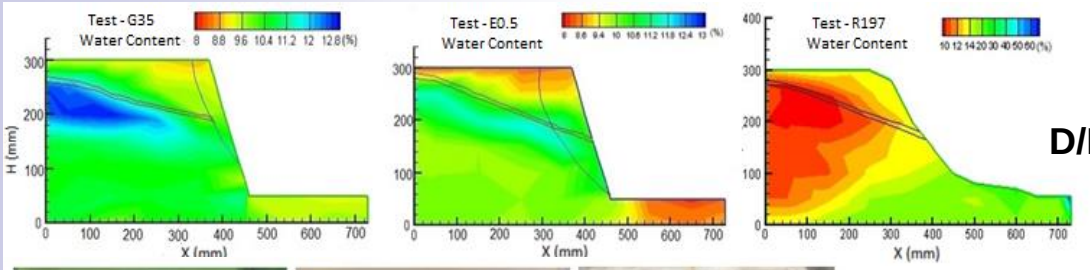
2.3 邊坡破壞行為-降雨因素

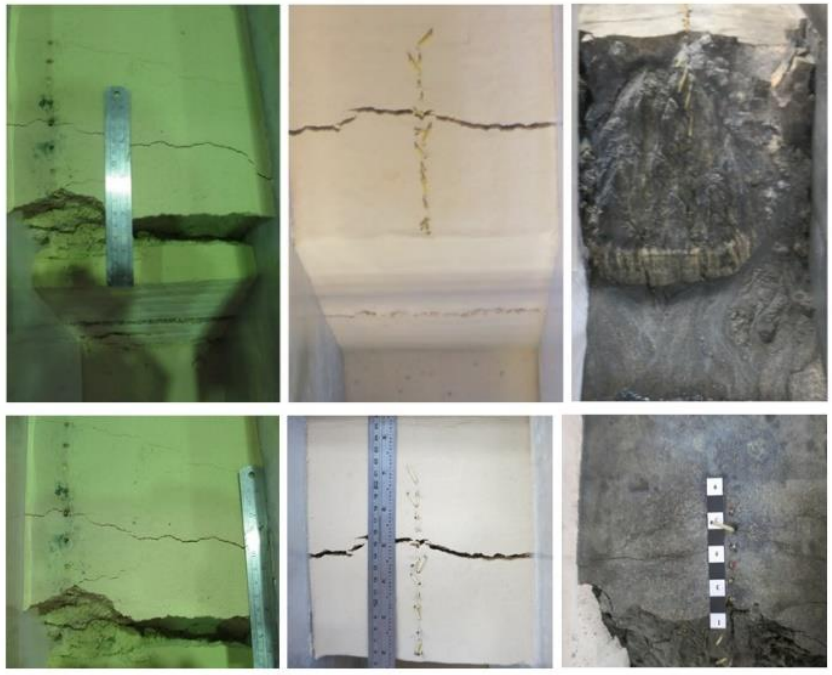
- 消耗區長度約 0.5H
- 堆積區長度約 0.53-0.64H



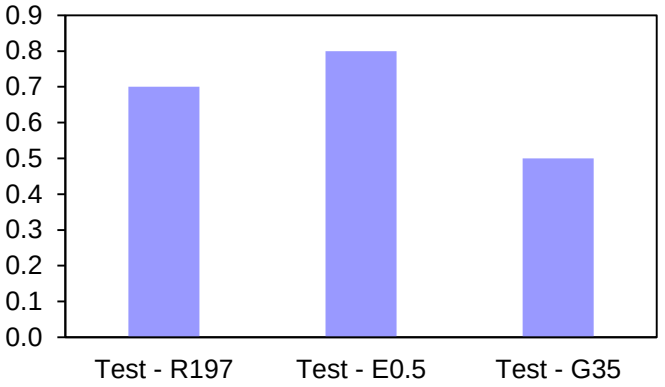
入滲範圍	Test – R197		Test – R88	
	Model (mm)	Prototype (m)	Model (mm)	Prototype (m)
張力裂縫	70 – 90	2.1 – 2.7 (0.28H – 0.36H)	….	….
其他區域	20 – 40	0.6 – 1.2 (0.08H – 0.16H)	15 – 20	0.45 – 0.6 (0.06H – 0.08H)
坡高 H = 7.5 m （模型坡高0.25 m，試驗離心力場30 g）				

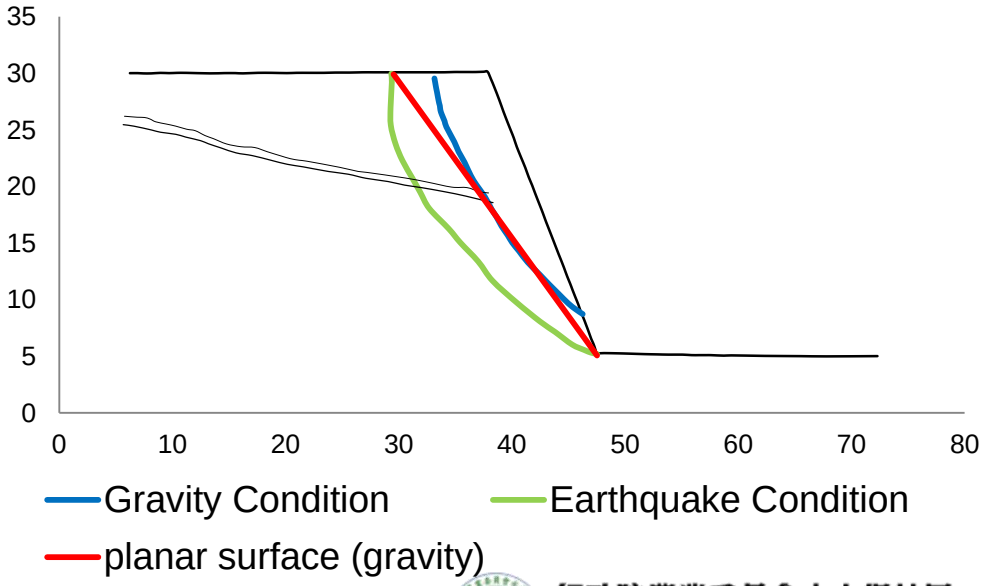
2.3 邊坡破壞行為-綜合比較





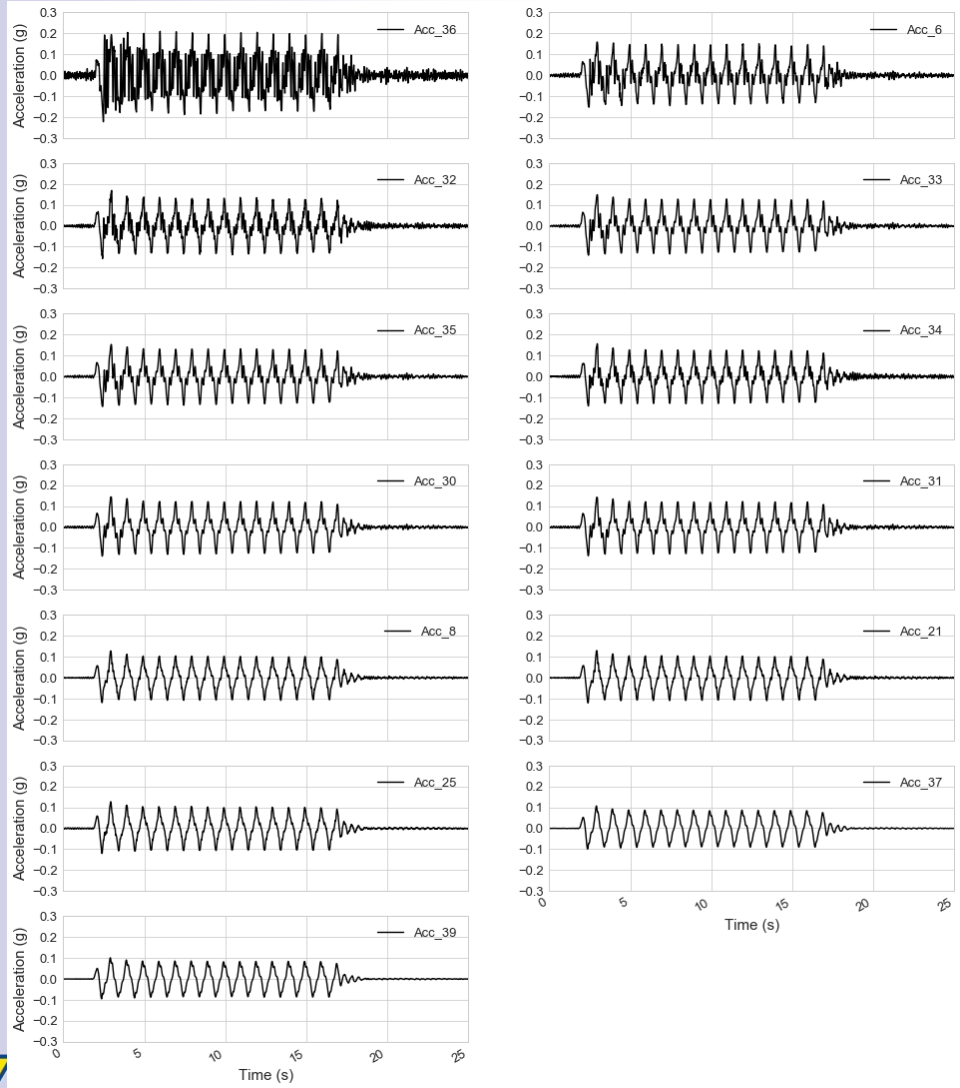
D/H



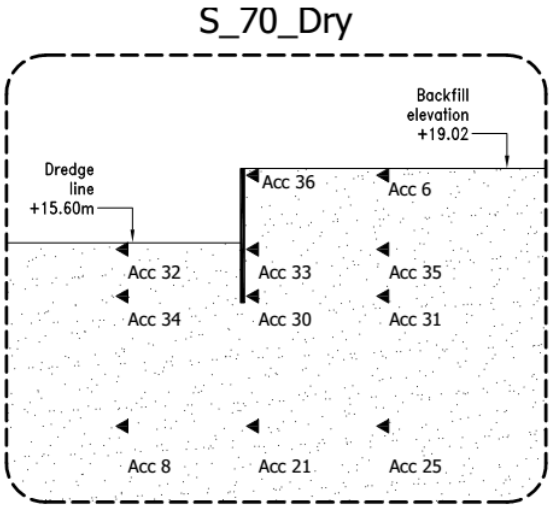


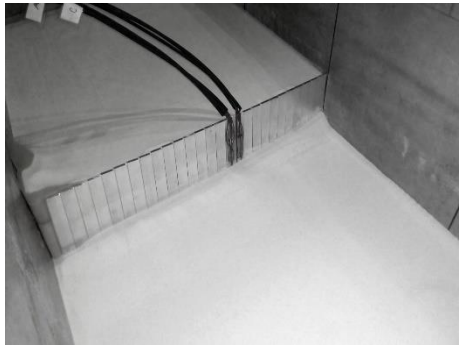
3.邊坡穩定方法之有效性評估

3.1 邊坡穩定方法之有效性評估-排樁牆



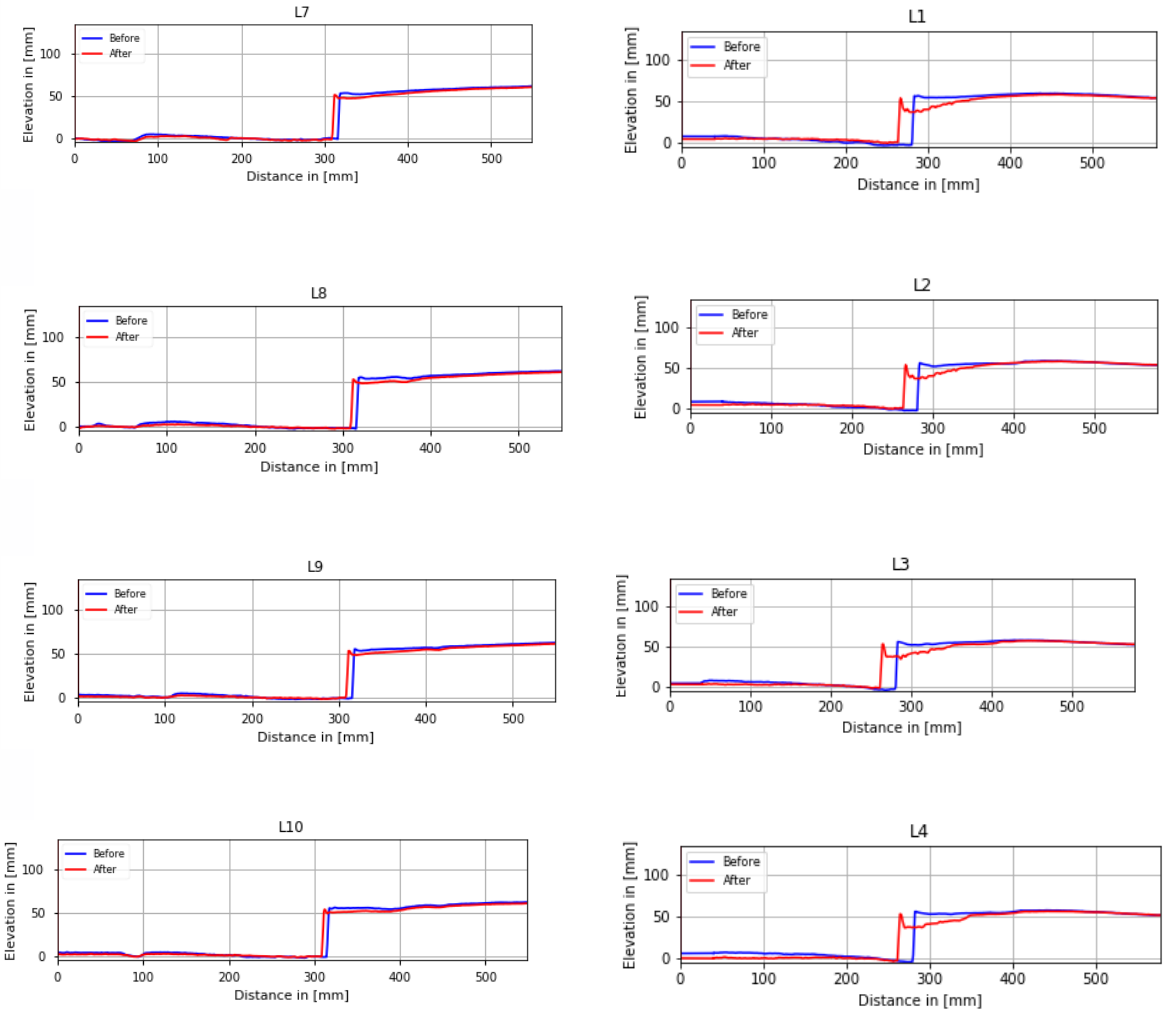
- 地層加速度放大行為與其他文獻之研究相符.





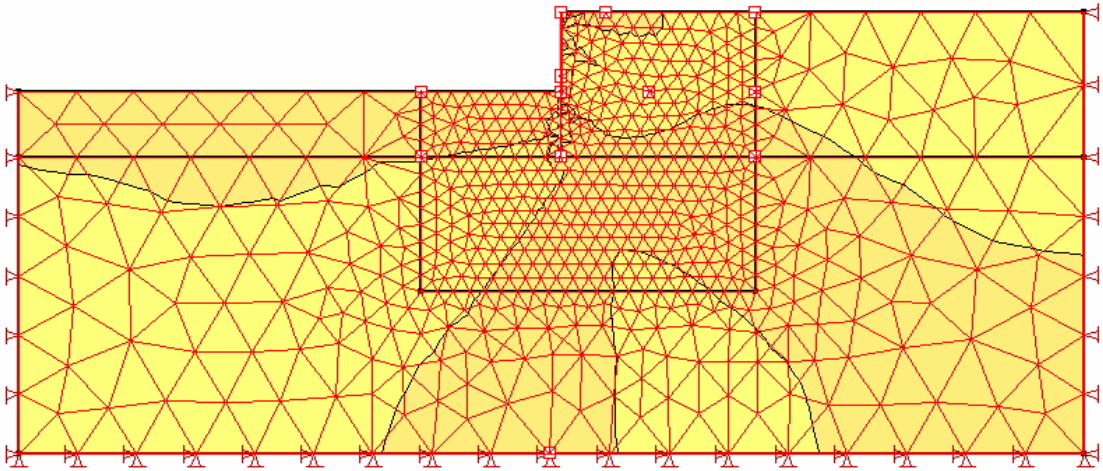
3.1 邊坡穩定方法之有效性評估-排樁牆

- 右圖為以雷射掃描所量測地表沉陷比較圖

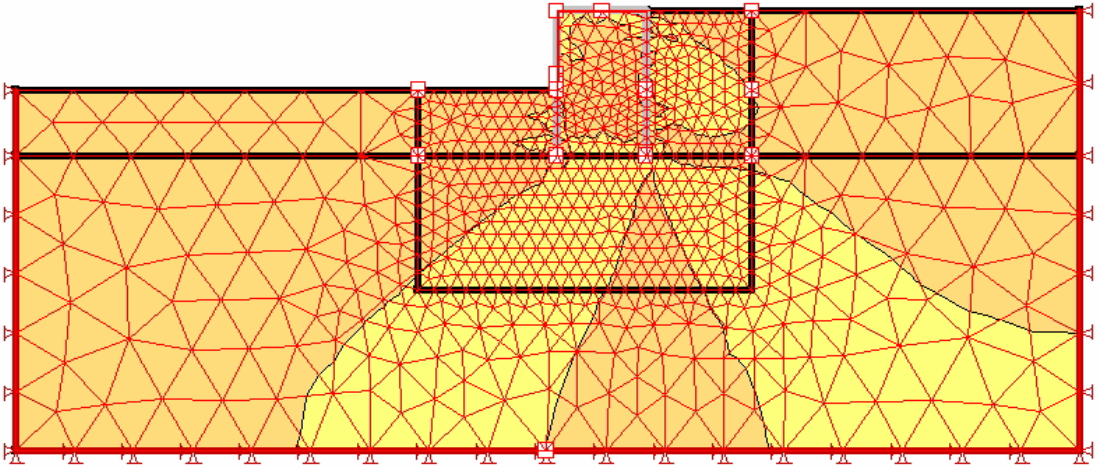


3.1 邊坡穩定方法之有效性評估-排樁牆

- 單排與雙排版樁牆的數值模型模擬結果



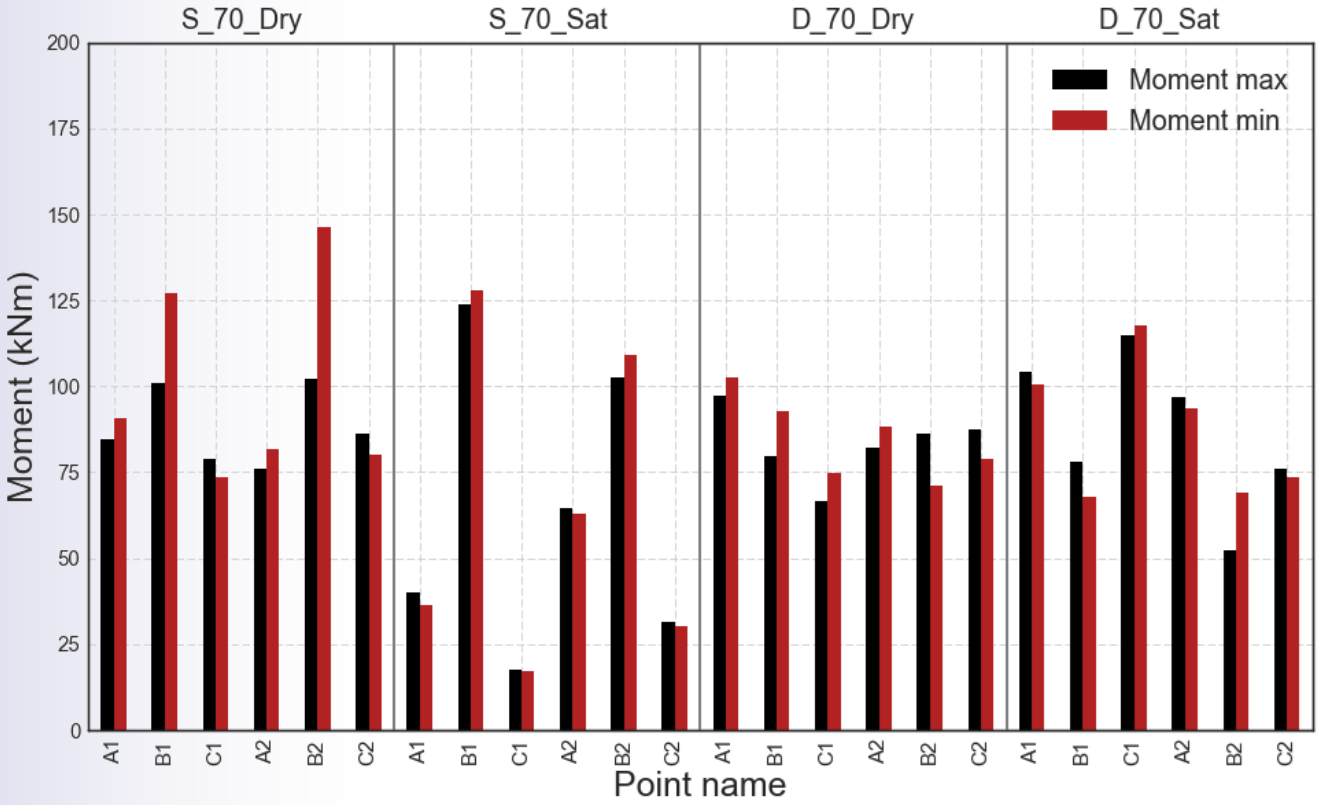
Single wall system (video)



Double wall system (video)

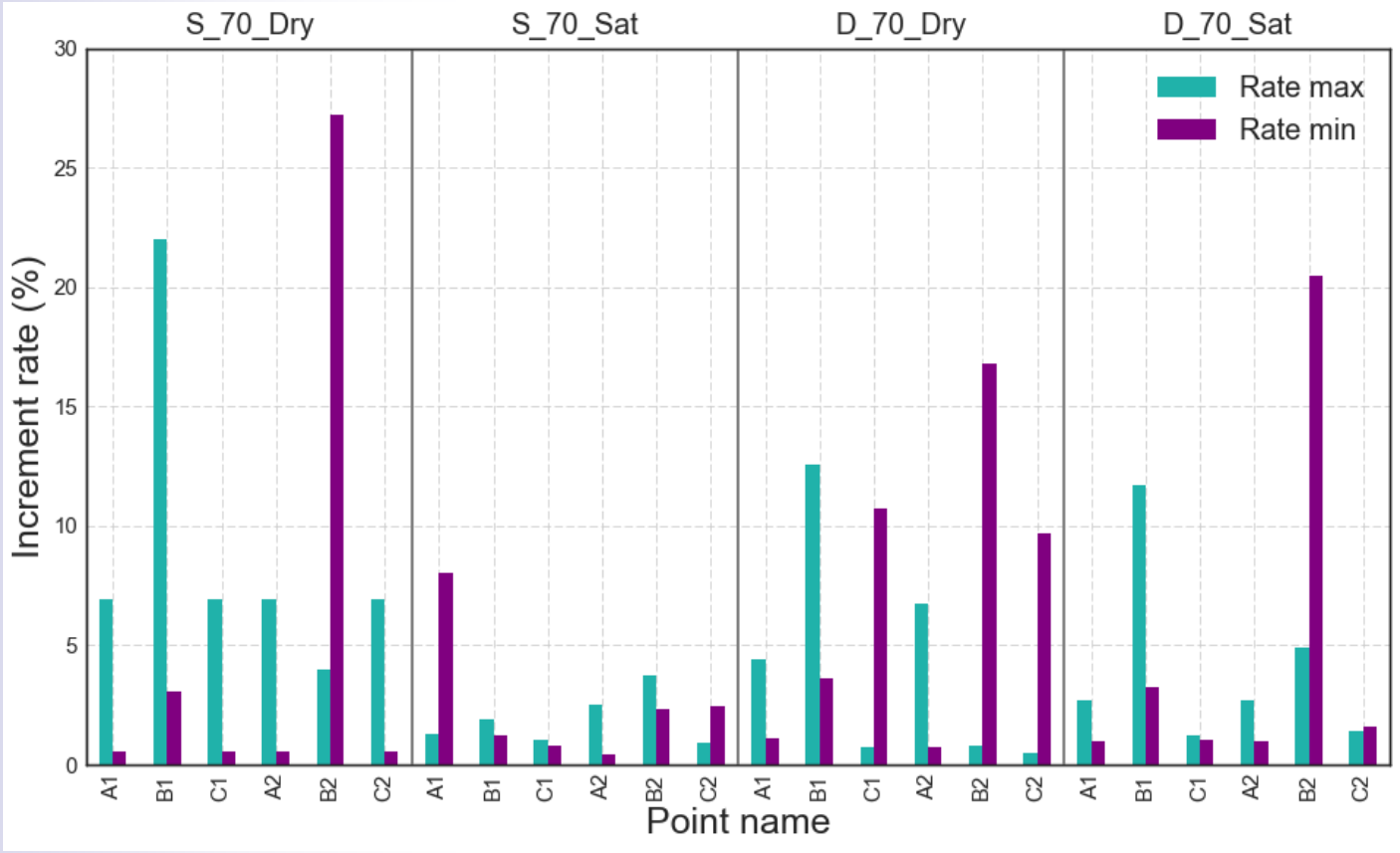
3.1 邊坡穩定方法之有效性評估-排樁牆

- 單層版樁牆之最大彎矩
- S_70_Sat 試驗為液化狀況，所以其具有最低之彎矩值



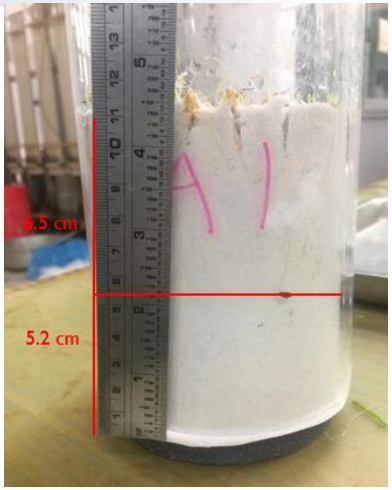
3.1 邊坡穩定方法之有效性評估-排樁牆

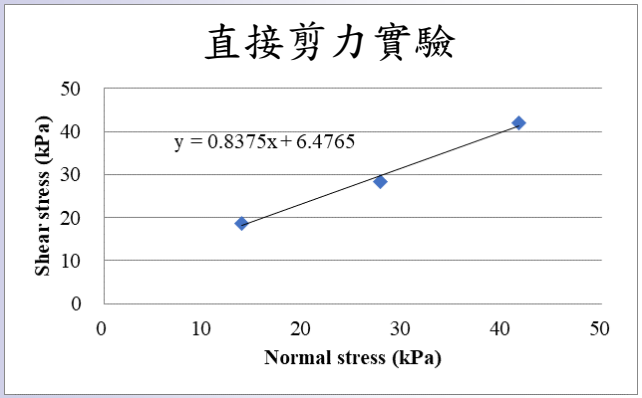
- 動態試驗與靜態試驗比較最大彎矩增加約30%



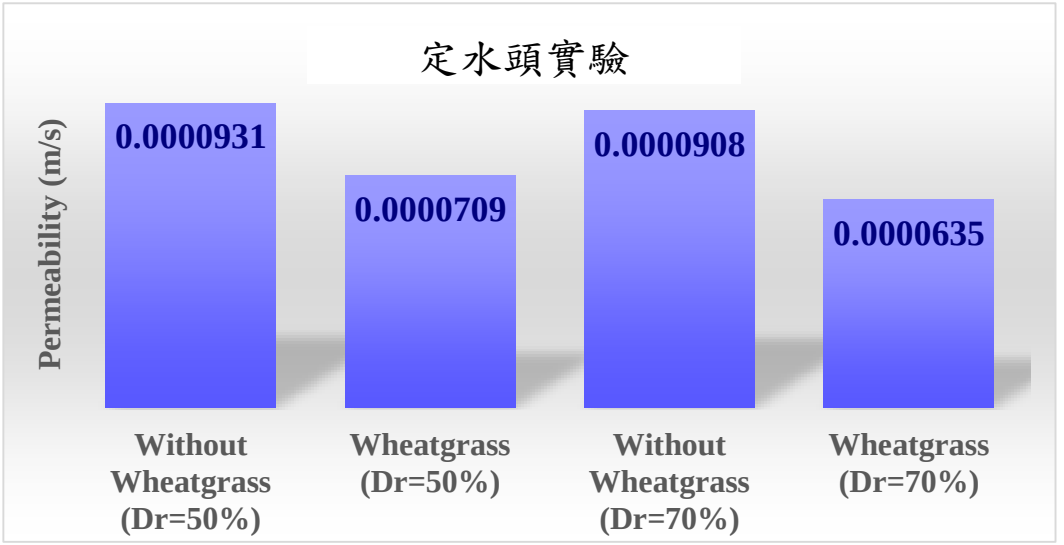
3.2 邊坡穩定方法之有效性評估-坡面植生

種植天數：5－8天
平均濕度： 75 %
平均溫度：30℃
土壤含水量：10 %



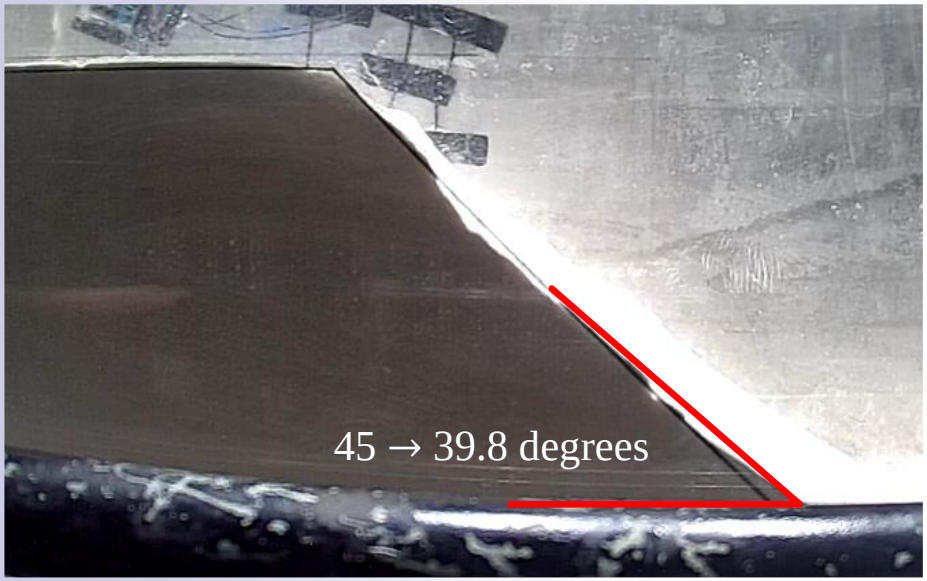


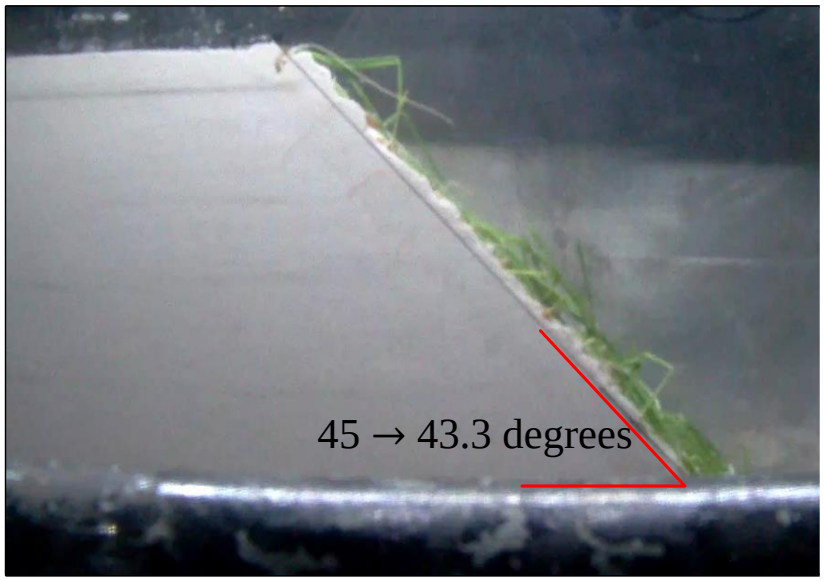
	Wheatgrass 1% - 1.14%	Without Wheatgrass
Friction angle (Degrees)	41.9	34.5
cohesion (kPa)	6.10	4.74



3.2 邊坡穩定方法之有效性評估-坡面植生

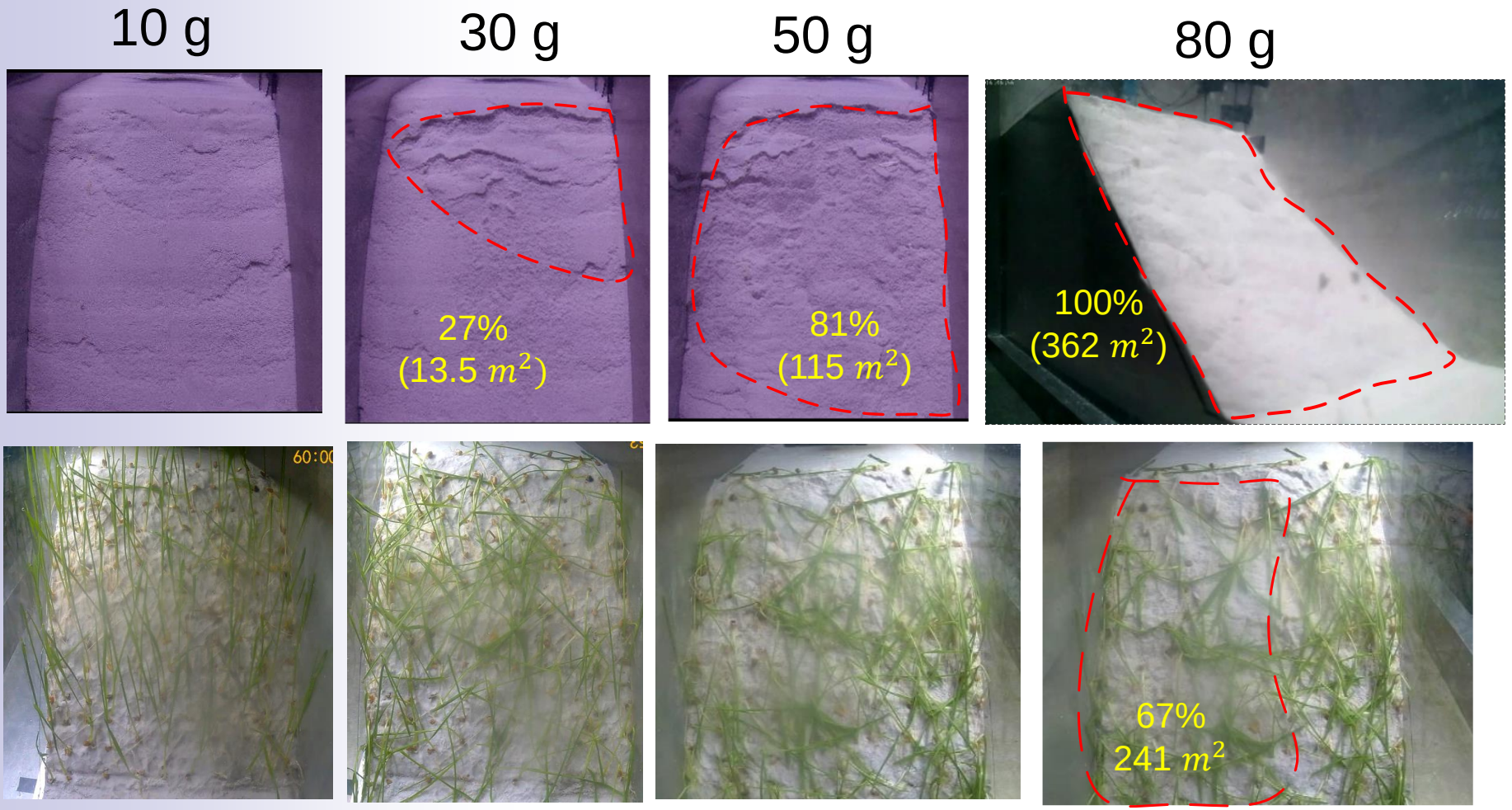
試驗名稱	試驗條件	g-level	Vegetation	Description
VGE_80g	45度緩坡具植生	80	是	逐步飛行至80倍地球重力場待模型穩定後，輸入基盤震動事件
GE_80g	45度緩坡無植生	80	否	





3.2 邊坡穩定方法之有效性評估-坡面植生

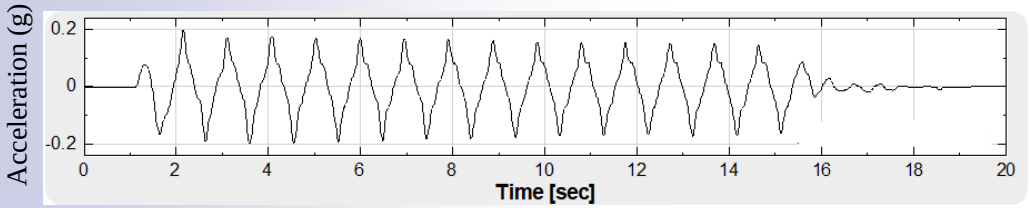
- 逐漸飛行至80倍地球重力場之過程



3.2 邊坡穩定方法之有效性評估-坡面植生

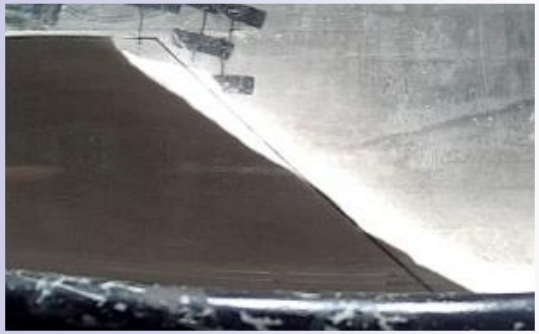
在80 g 時的基盤輸入震動

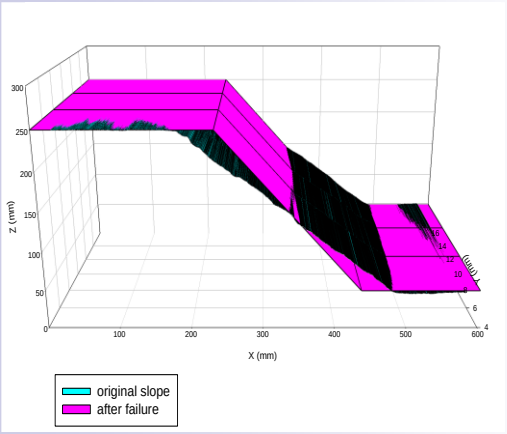
- 等振幅類正弦波
- 頻率：1 Hz（模型 30 Hz）
- 週期：15週期
- 延時： 15 sec（模型 0.5 sec）
- 最大基盤加速度（PBA）： 0.2 g（模型6 g）

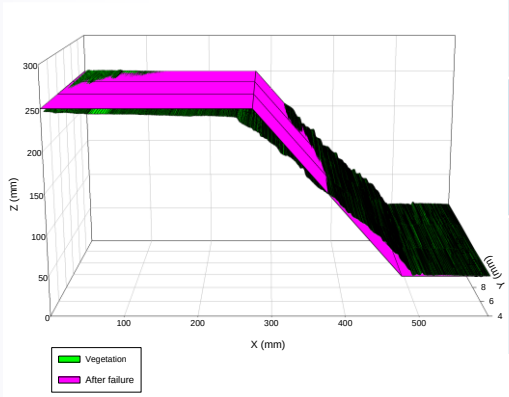


3.2 邊坡穩定方法之有效性評估-坡面植生

- 滑動與堆積體積 (Earthquake)







	GE_80g	VGE_80g
堆積體積 (m^3)	301	273
崩塌體積 (m^3)	390	269
最大堆積高度	0.18 H	0.14 H
最大消耗高度	0.20 H	0.14 H

3.3 邊坡穩定方法之有效性評估- C-RHA微型樁加固

- 混凝土(Concrete, C)-生物碳(Rice Husk Ash, RHA)微型樁加固工法

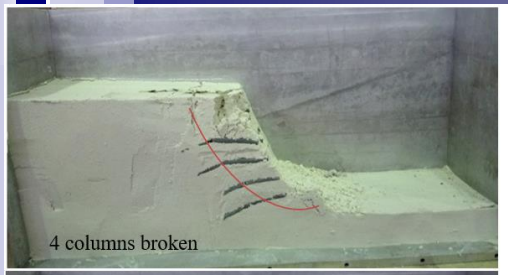
Column mix design

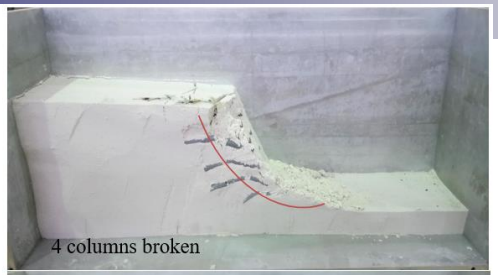
Cement : Sand : Rice Husk Ash
0.9: 2 : 0.1
w/c=0.45

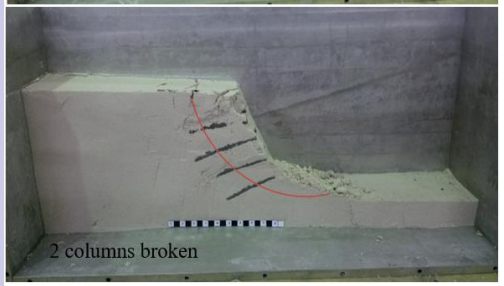
Chemical Composition (%)	Cement	SF	RHA
SiO_2	22.52	94	82.9
Al_2O_3	5.80	0.21	0.29
Fe_2O_3	3.52	0.09	1.83
SO_3	2.54	-	1.34
CaO	62.08	0.12	2.29
MgO	1.55	0.33	0.93
Na_2O	0.05	-	0.06
K_2O	0.56	0.38	6.82
L.O.I.	0.94	1.2	1.5

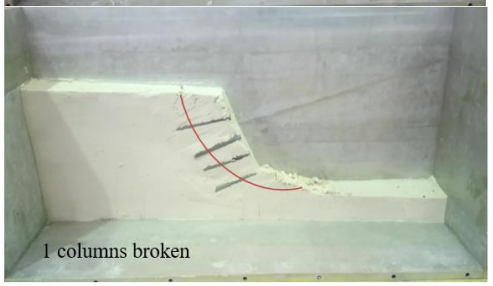
- 增加強度與耐久性
- 減少水泥使用量(10%)
- 廢棄物再利用減少二氧化碳產生

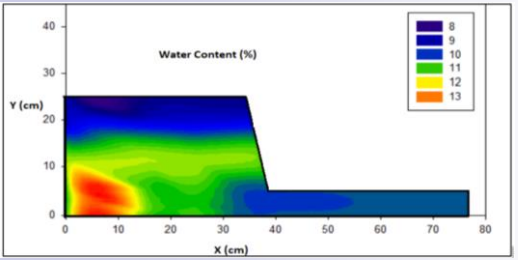
3.3 邊坡穩定方法之有效性評估- C-RHA微型樁加固

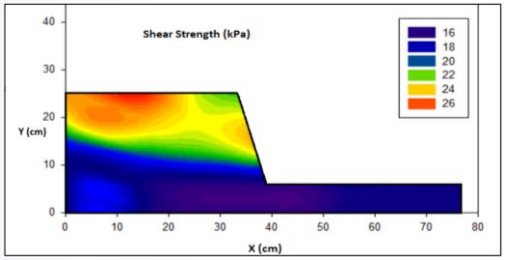


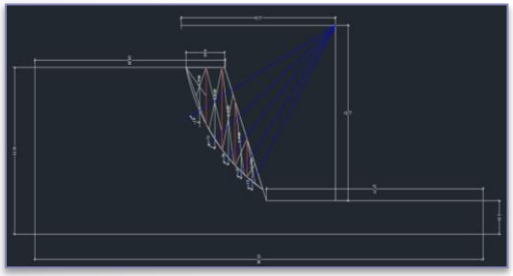


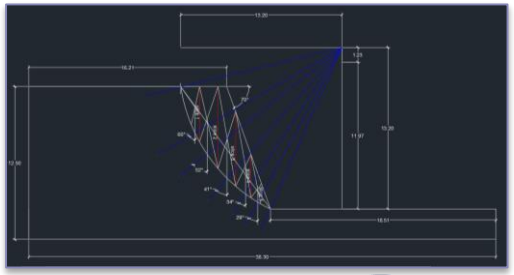






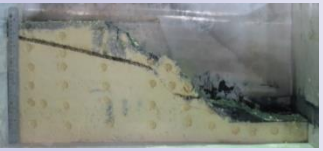


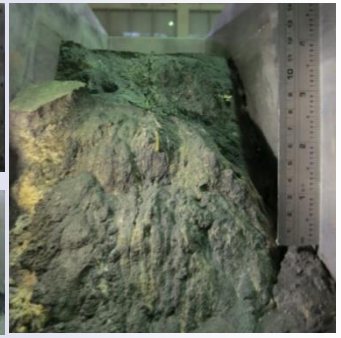




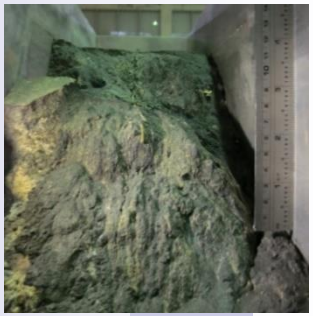
4. 小結

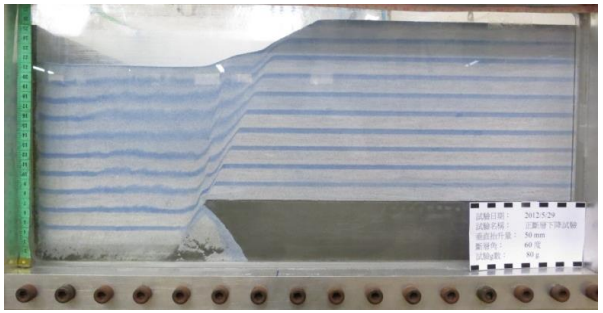
- 對具有堅實基礎的邊坡，地震引致的破壞區域會大於重力與降雨沖蝕的影響。
- 物理模型模擬的初始條件（例如材料不均勻性與既存弱面等）及輸入條件，對試驗結果的影響非常顯著，必須詳細記錄與比對，以作為數值模型輸入參數之驗證。
- 離心模型試驗在大地工程與水土保持工程是相當有效的工具。

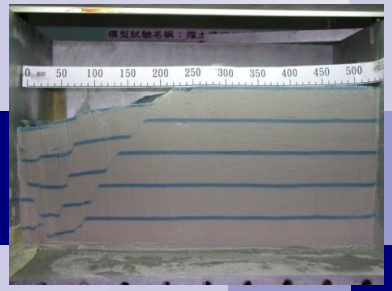


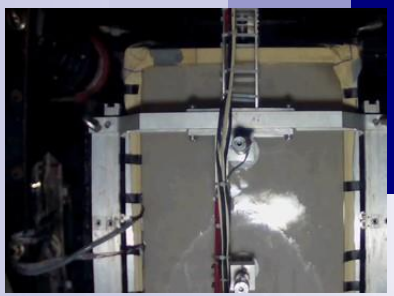


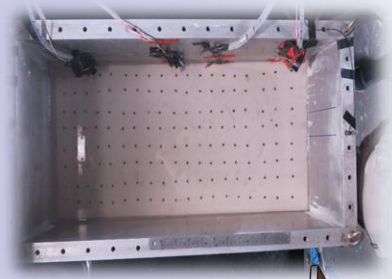















謝謝聆聽
敬請指教

行政院農業委員會水土保持局
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