國立中央大學

National Central University








以離心模型模擬植物根系對邊坡穩定性的影響

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NCU CENTRIFUGE GEOTECHNICAL PHYSICAL MODELING

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03 土壤試驗結果

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01

前言

前言

Geological factor
(soil composition)

1

Earthquake-induced
landslide
(Kumamoto
Earthquake 7.3 M)



Hydrological factors
(intense rainfalls)

2

Rainfall-induced
landslide
(Xiaolin village,
Kaohsiung, Taiwan)



Human interventions
(slope excavation)

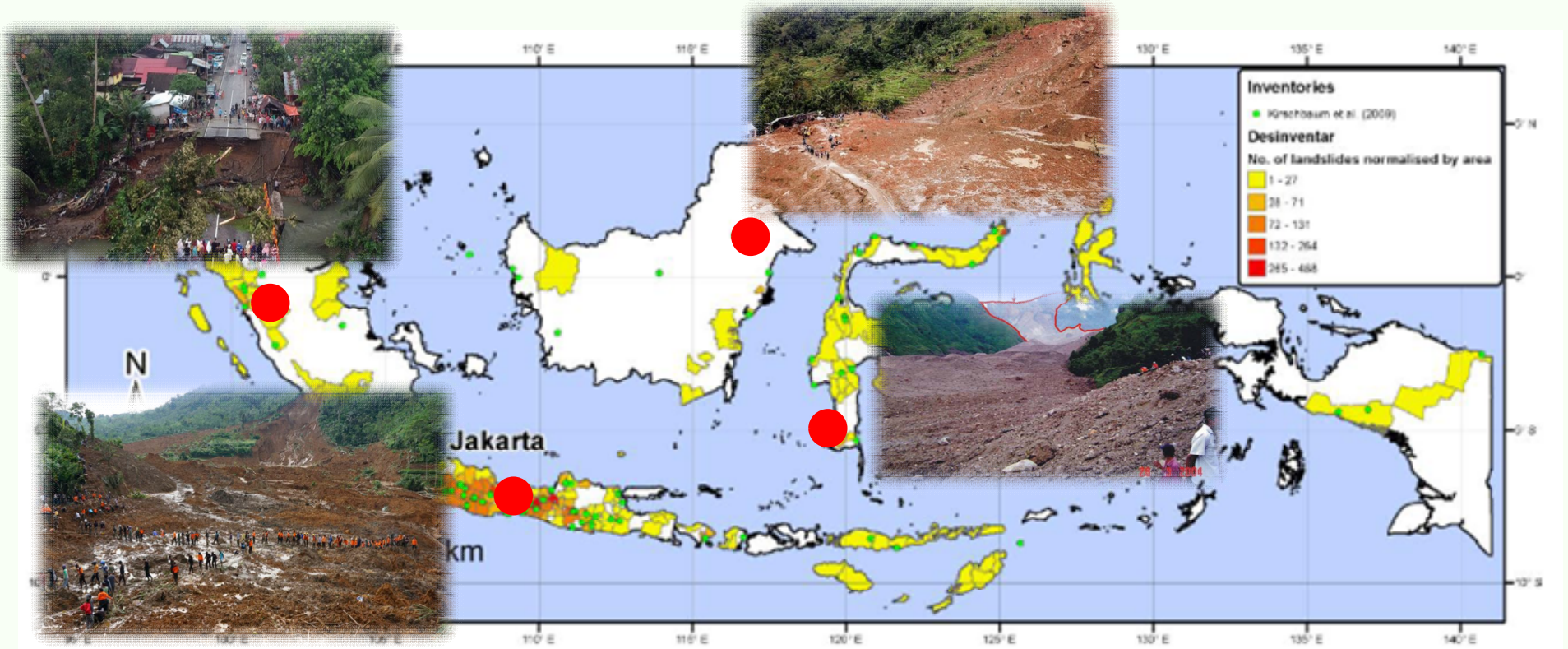
3

Gravity force-induced
landslide
(Formosa freeway,
Keelung City, Taiwan)



NCENTRIFUGE GEOTECHNICAL PHYSICAL MODELING

前言


Inventories
Desinventar
No. of landslides normalised by area
1 - 27
28 - 71
72 - 131
132 - 264
265 - 488
N
Jakarta
km

文獻回顧

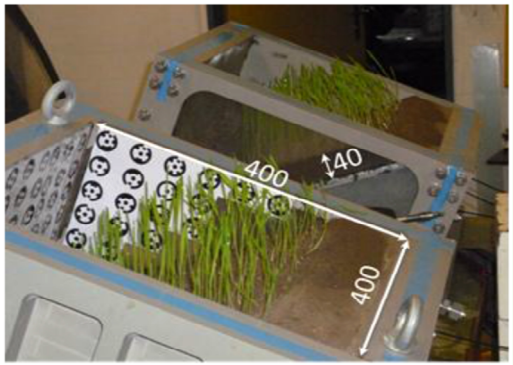
Amin Askarinejad and Sarah Marcella Springman (2014)

Centrifuge modeling tests to simulate vegetation behavior on silty sand slope subjected to rainfall.

Results: (1) larger deformations might be expected prior to failure in the slopes with well developed network of roots if compared to the non vegetated slopes, and (2) the vegetated slopes were very well drained during the rainfall compared to the non vegetated slopes

Term [Dimension]	Prototype	Model
Length (macroscopic) [L]	1	1/N
Seepage velocity (macroscopic and grain scale) [L/T]	1	N
Seepage time (macroscopic) [T]	1	$1/N^2$
Total rain [L]	1	1/N
Rain duration [T]	1	$1/N^2$
Rain intensity [L/T]	1	N
Length (particle scale) [L]	1	1
Seepage time (grain scale) [T]	1	1/N
Hydraulic gradient (macroscopic) [L/L]	1	N
Hydraulic gradient (grain scale) [L/L]	1	N

Scaling law



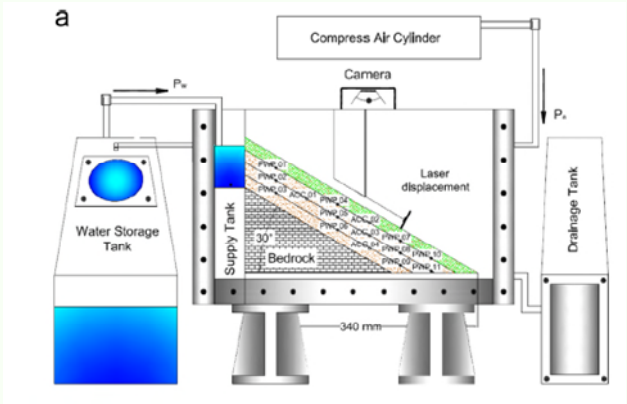
Avena sativa planted in the centrifuge models

文獻回顧

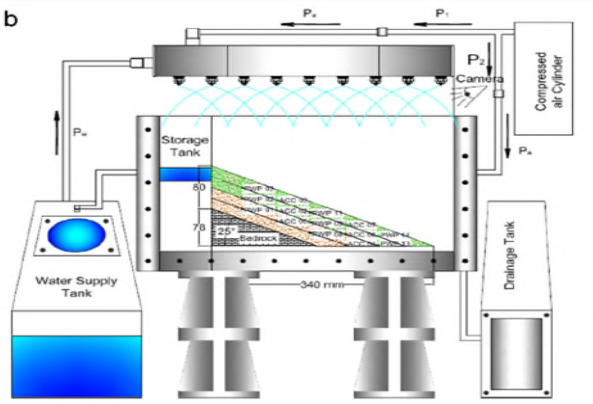
Kreng Hav Eab, Suched Likitlersuang, and Akihiro Takahashi (2015)

Laboratory and modelling investigation of root-reinforced system for slope stabilisation.

Results: (1) Shear strength of the soil depends on the root length and the root area ratio, (2) The rise of water table can decrease the shear strength of the effective stress, (3) Roots fibers on the slope surface help to prevent crack on the soil slope, (4) Vegetation roots in the slope stability have an ability to reduce both the infiltration rate into the ground and the rising of groundwater table



Seepage model test



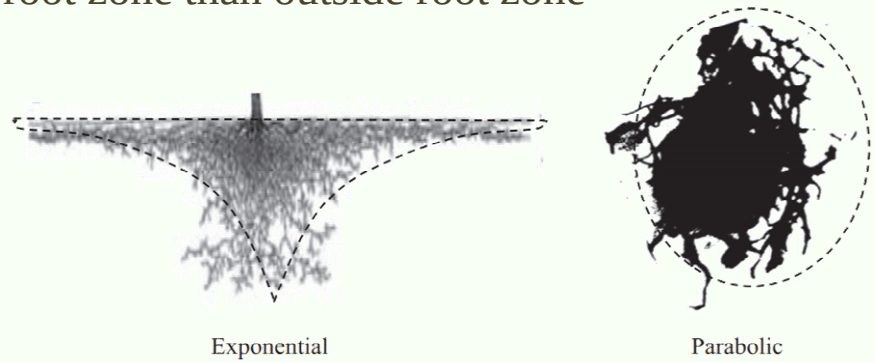
Rainfall model test

文獻回顧

H.W. Liu., S. Feng., and C.W.W. Ng (2016)

Analytical analysis of hydraulic effect of vegetation on shallow slope stability with different root architectures.

Results: (1) during the first one hour of rainfall, exponential root architecture has higher ability than that of parabolic root to maintain shallow slope stability, due to the lower initial pore-water pressure induced by exponential root architecture, and (2) for the parabolic root architecture (more critical one), under the light rainfall intensity of 20 mm/day for 24 h, hydraulic effects of vegetation are more pronounced inside root zone than outside root zone



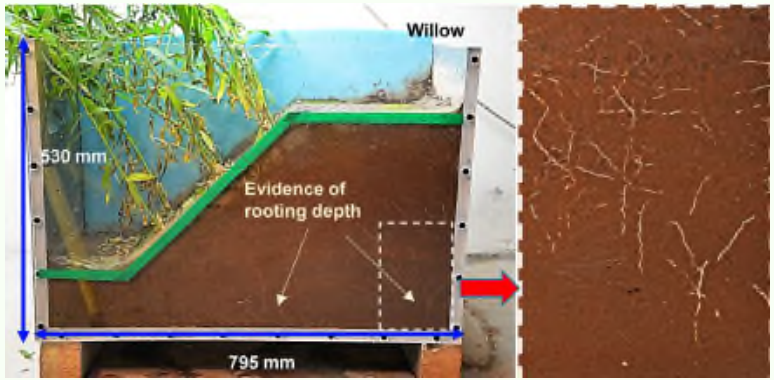
Different real root architectures

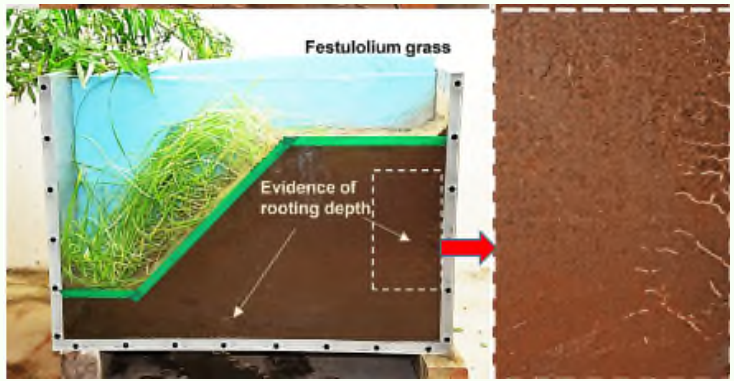
文獻回顧

T. Liang (2017)

Scaling of the reinforcement of soil slopes by a living plants in a geotechnical centrifuge.

Results: (1) use of juvenile plants could potentially produce prototype root systems that are highly representative of corresponding mature root systems, (2) the most significant contributions of roots to soil strength are mainly located in the shallow soil layer, and (3) to minimize potential grain size effects on the root-soil interaction, the lowest possible N is preferred (in this study N = 15)





Selection of a suitable scaling factor for centrifuge modeling

文獻回顧

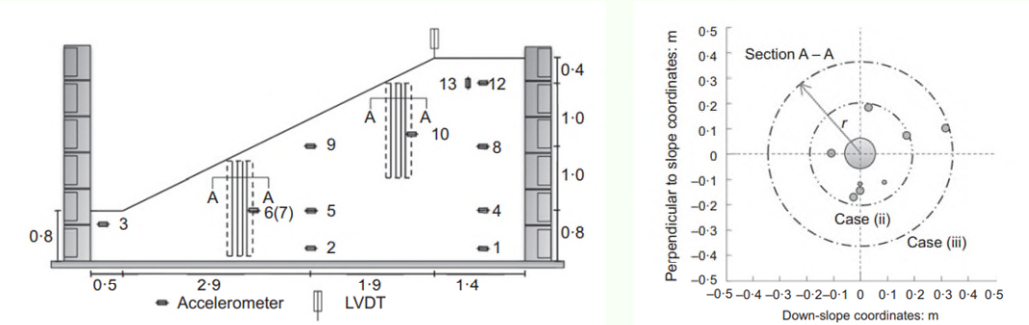
Liang, T., Knappett, J.A., Duckett, N (2015)

Modelling the seismic performance of rooted slopes from individual root-soil interaction to global slope behaviour.

Aim of test: Dynamic centrifuge testing has been performed to investigate the performance of slopes containing root analogues under a sequence of earthquake motions.

Summary of test: (1) Eight successive earthquake motions were applied to each model at 10g, comprising three types with distinct peak ground acceleration (PGA), duration and frequency content, (2) the ABS plastic was selected as a material potentially having a very similar Young's modulus and ultimate tensile strength to real roots.

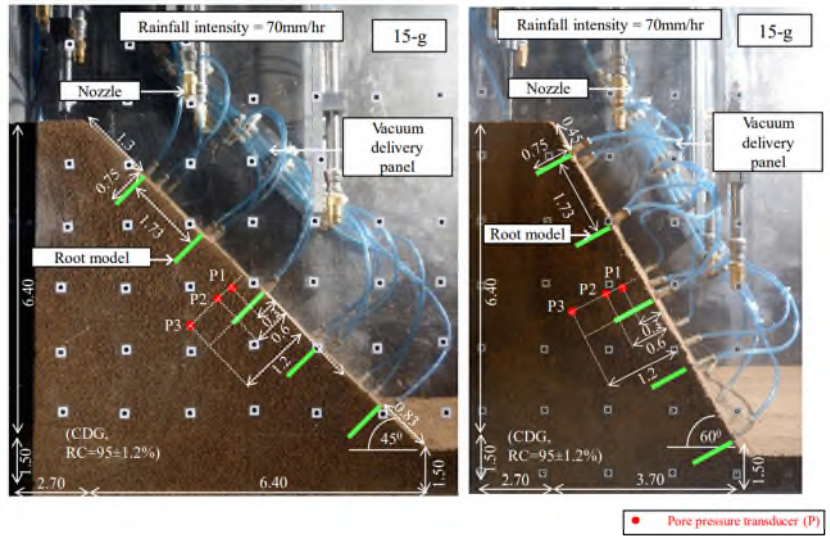
Result: The presence of root analogues highly reduced the permanent slope settlement (61%) compared with the unreinforced cases.



Slope configuration and distribution of root group

文獻回顧

Leung, A.K., Kamchoom, V., Ng, C.W.W (2017)
Influences of root-induced soil suction and root geometry on slope stability: a centrifuge study.
Aim of test: to investigate the effectiveness of using plant roots for shallow slope stabilization, with dual consideration of transpiration-induced suction and mechanical root reinforcement.
Results: (1) Tap-shaped root geometry was able to stabilize a 45 degrees slope for an intense rainfall event with a return period of 1000 years, (2) The greater hydrological and mechanical effects provided by the heart-shaped roots hence resulted in greater shallow stability of the slope.

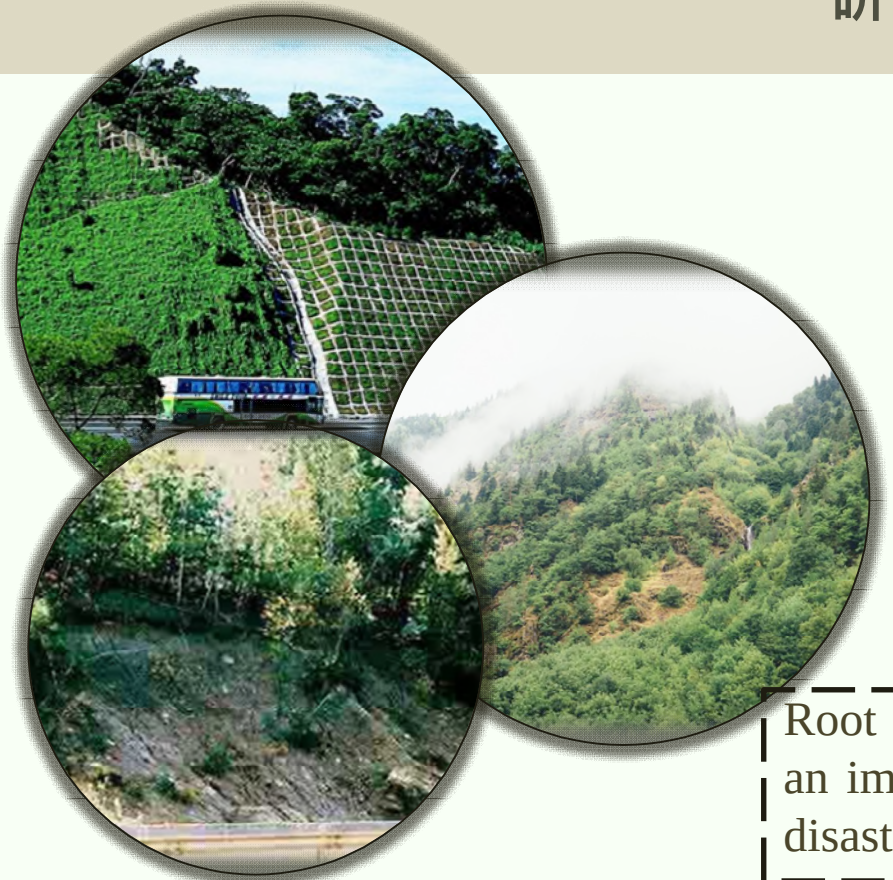


Slope configuration

文獻回顧總結

Author	Method	Type of reinforcement	G-level (g)	Slope angle (degrees)	Condition
Askarinejad (2014)	Centrifuge modeling	Oat grass	50	38	Rainfall
Kreng (2013)	Centrifuge modeling	*Vetiveria sp.* Fiber polyester	50	30	Rainfall Seepage
Liang (2015)	Centrifuge modeling	ABS plastic	10	27	Earthquake
Liu (2016)	Analytical analysis	Parabolic and exponential root types	-	35	Rainfall
Liang (2017)	Centrifuge modeling	Willow Festulolium grass Gorse	15	45	Hydrological condition
Leung (2017)	Centrifuge modeling	*Schefflera heptaphylla* *Rhodomyrtus tomentosa*	15	45 and 60	Rainfall

研究目的



To evaluate the impact of increasing gravitational acceleration conditions on the stability of the root-reinforced slope.

To evaluate the effect of different type of roots system and their distribution to the slope failure mechanism.

Root reinforcement has been recognized to play an important role for the stability against natural disaster triggered shallow landslides.

NCENTRIFUGE GEOTECHNICAL PHYSICAL MODELING

02 試驗設備及材料

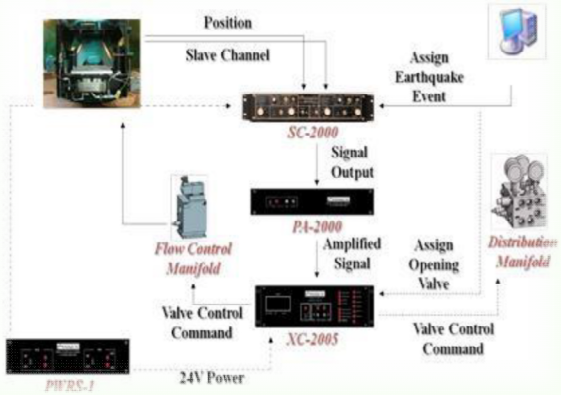


中央大學地工離心機

NCU geotechnical centrifuge



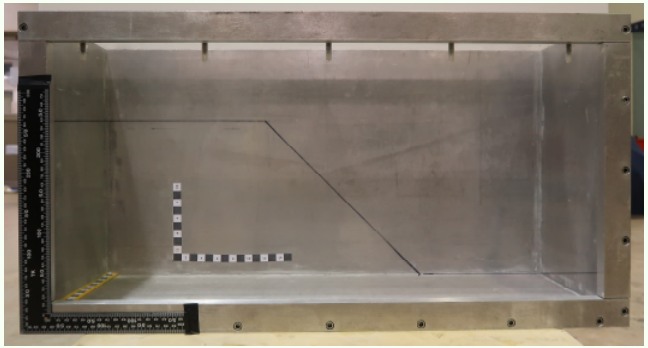
Nominal radius : 3 meter
Machine capacity : 100 g-ton
Maximum rotation speed : 265 rpm
Maximum acceleration : 200 g



NCU geotechnical centrifuge shaking table

Shaking table type : Servo hydraulic single acting system
Shaking type : Periodic or random determined type
Shaking direction : One direction
Normal shaking force : ± 53.4 kN
Maximum shaking velocity: ± 1 m/s
Maximum payload area : 1 m × 0.5 m (length × width)
Maximum payload : 400 kg
Maximum acceleration : 80 g

試驗箱及感測器



Container with transparent window



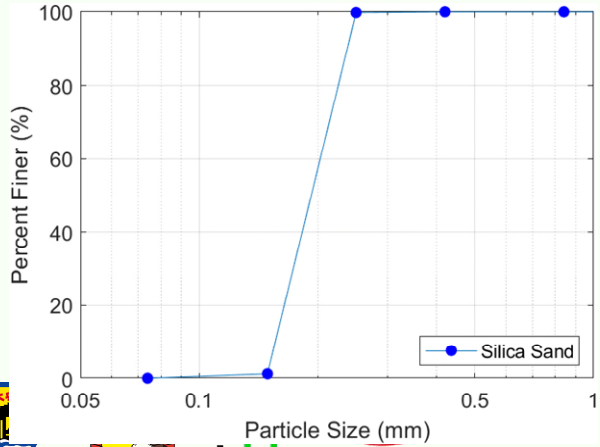
Camera



LDT

試驗材料



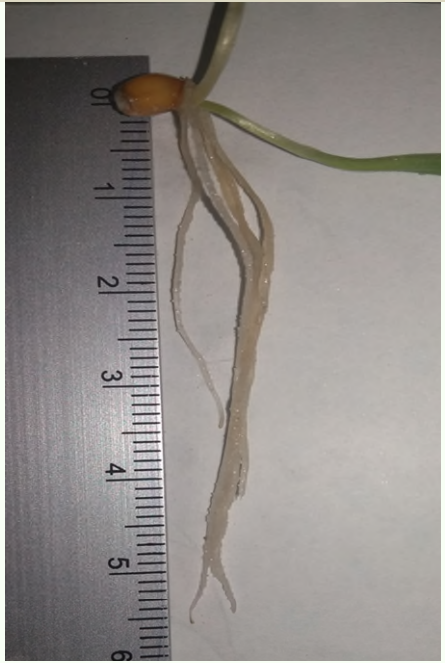


Soil Properties

Soil type	: Quartz sand
Specific gravity	: 2.65
D_{50}	: 0.19 mm
D_{10}	: 0.15 mm
Friction angle	: 34.5°
Maximum unit weight	: 16.30 kN/m³
Minimum unit weight	: 14.10 kN/m³

Unified Soil Classification System: SP (Poorly graded sand)

邊坡模型植被之根系種類



Wheatgrass /小麥草
(*Agropyron cristatum*)
鬚根 **(Fibrous root)**



Adzuki Bean /红豆
(*Vigna angularis*)
側根 (Lateral root)



Sunflower (向日葵)
(*Helianthus sp.*)
主根及毛狀次生根
(Single taproot and hairy secondary root)



03

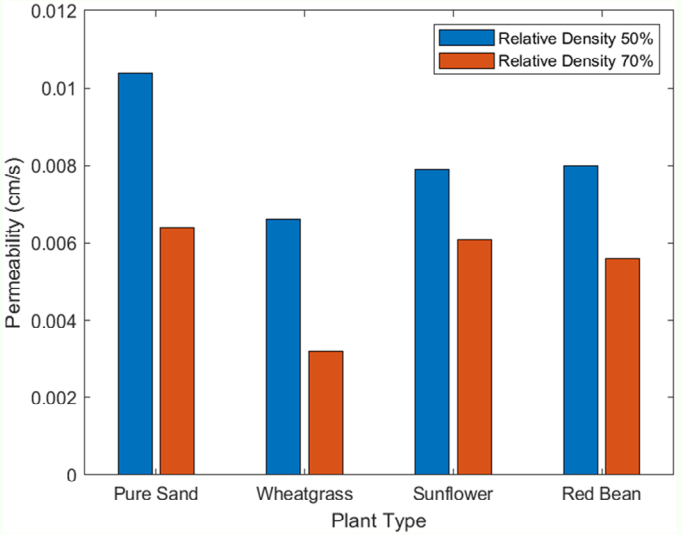
土壤試驗結果

土壤試驗結果

直接剪力試驗

Test name and properties	Engineering properties		
	Cohesion (kPa)	Friction angle (°)	Permeability (cm/s)
Pure sand Dr 50%	0.18	30.39	0.0104
Pure sand Dr 70%	0.93	36.87	0.0064
Wheatgrass Sp 2 Dr 70%	2.33	38.80	0.0032
Wheatgrass Sp 2 Dr 50%	3.42	32.02	0.0066
Sunflower Sp 2 Dr 70%	1.62	36.87	0.0061
Sunflower Sp 2 Dr 50%	2.26	33.02	0.0079
Red bean Sp 2 Dr 50%	2.31	34.02	0.0080
Red bean Sp 2 Dr 70%	2.66	39.52	0.0056

滲透性試驗



土壤試驗結果

含水量試驗

Water content	
Plant type	**Water content (%)**
Sunflower Dr=50%	12.553
Sunflower Dr=70%	13.099
Wheatgrass Dr=50%	7.939
Wheatgrass Dr=70%	7.507
Red Bean Dr=50%	12.129
Red Bean Dr=70%	13.395

ROOT AREA RATIO (RAR)

Root area ratio (RAR)	
Type of plant	**RAR (%)**
Sunflower Dr=50%	0.132
Sunflower Dr=70%	0.145
Wheatgrass Dr=50%	0.521
Wheatgrass Dr=70%	0.868
Red Bean Dr=50%	0.846
Red Bean Dr=70%	1.047

NCU NCENTRIFUGE GEOTECHNICAL PHYSICAL MODELING



04

離心模型試驗結果

離心模型試驗條件



Experimental Program

Water content : 10%

Relative density : 50%

Dry unit weight : 14.85 kN/m³

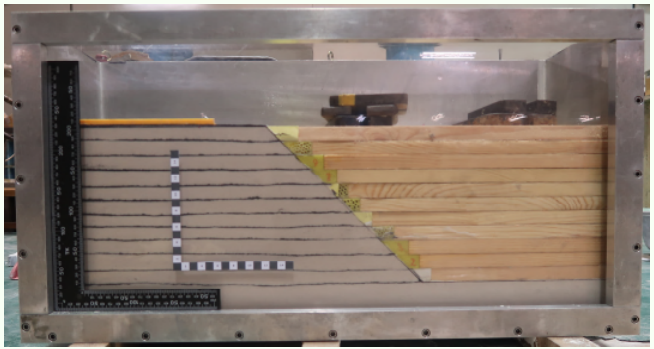
Spacing of seed : 20 mm

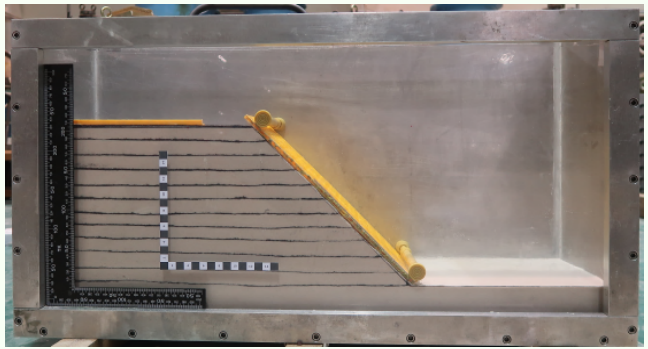
Root area ratio : 1% ~ 1.4%

Compaction method: Weight tamping

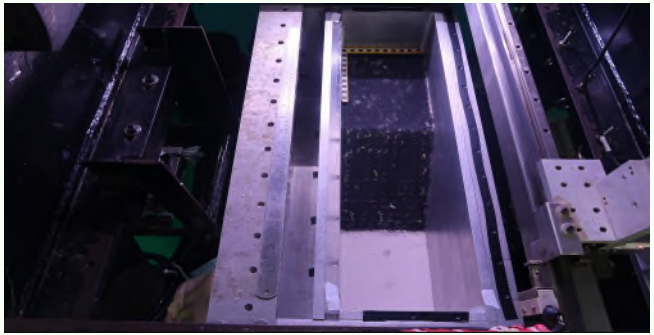
NCU GEOTECHNICAL PHYSICAL MODELING

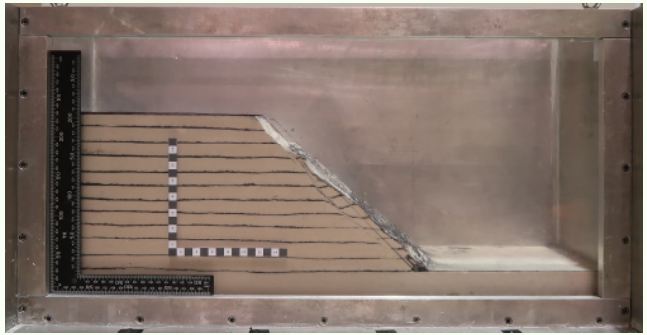
離心模型試體準備









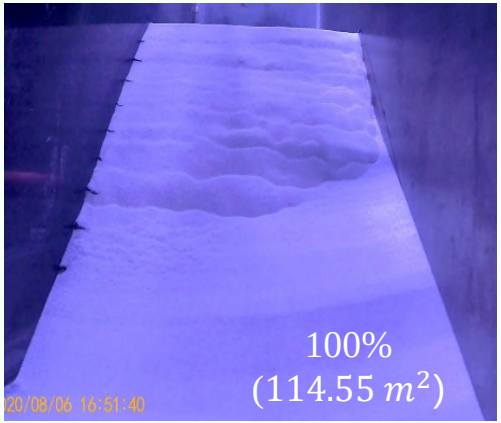




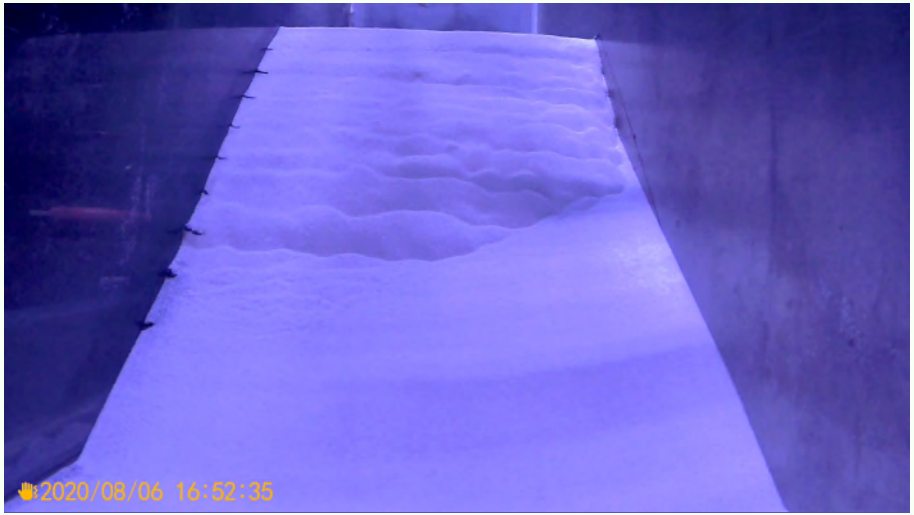
試驗結果 - 無根系邊坡 (對照組)



1g

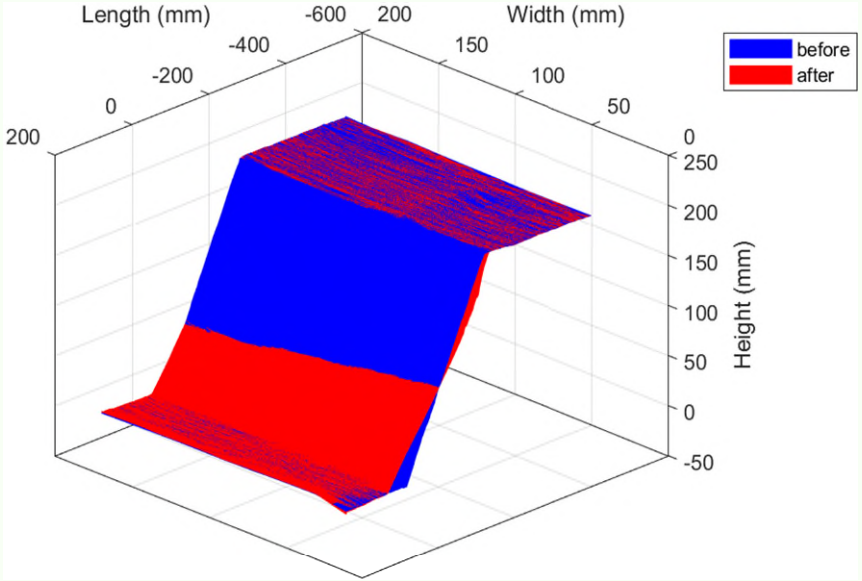


45g

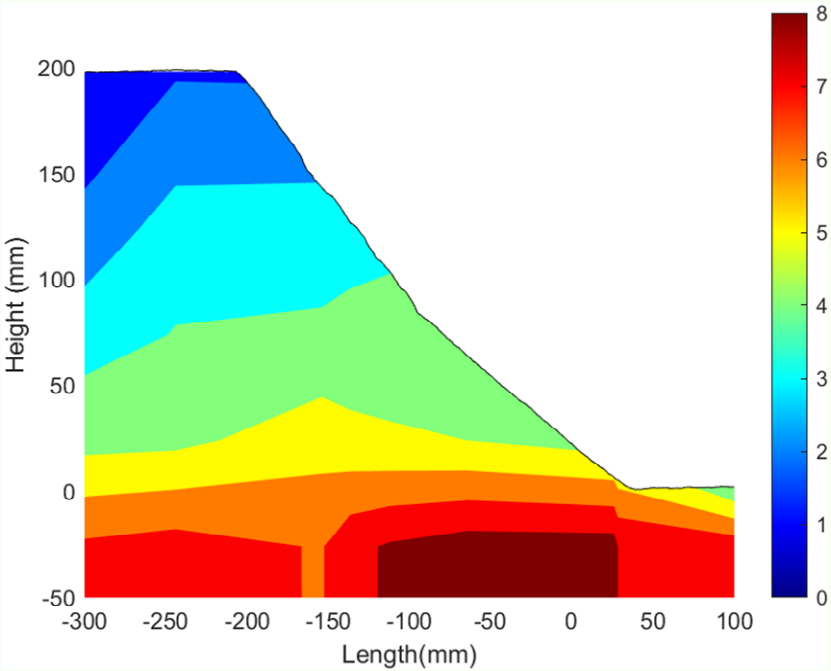


(G_45g) result

試驗結果 - 無植被邊坡 (對照組)



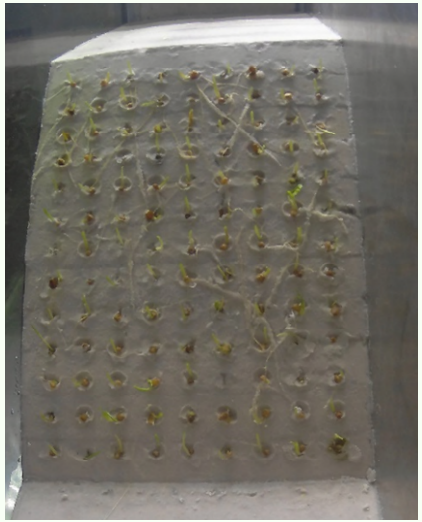
Depletion (m^3)	Accumulation (m^3)
105.83	136.94



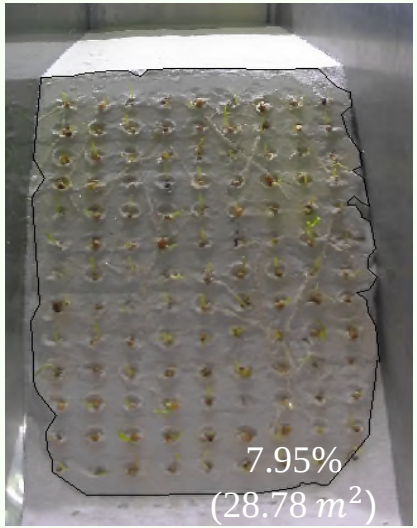
Water content distribution (%)

(G_45g) result

試驗結果 – 鬚根系植被邊坡



1g



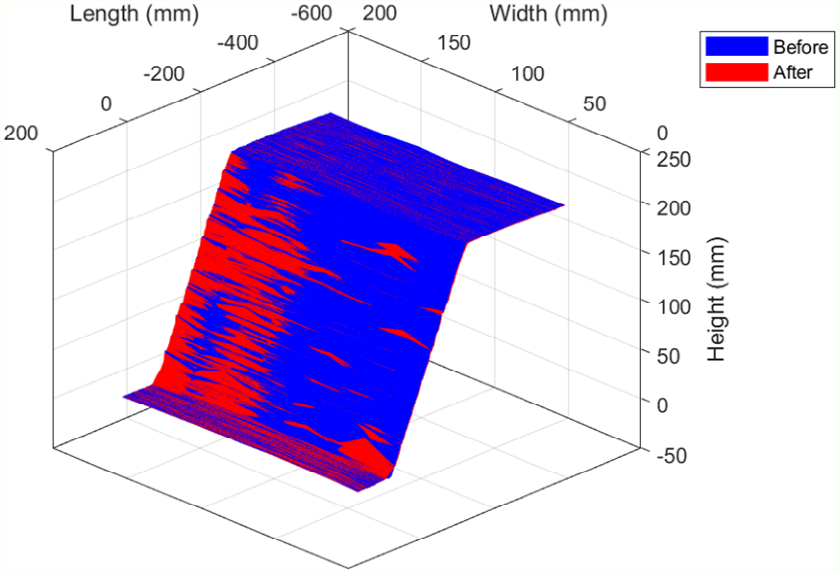
80g

鬚根 (Fibrous root)

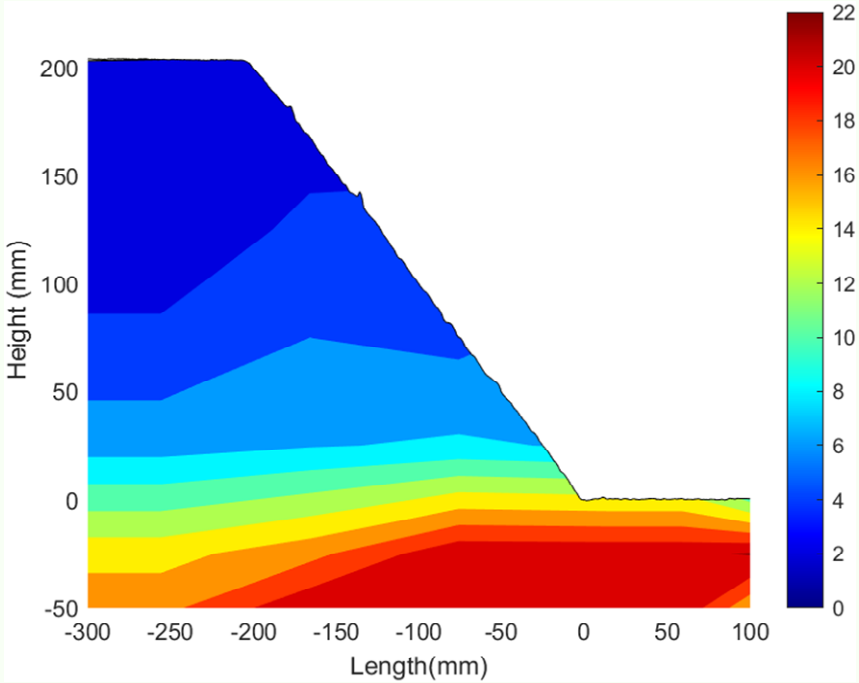


(VG_WG80g) result

試驗結果 – 鬚根系植被邊坡



Depletion (m^3)	Accumulation (m^3)
20.15	12.71



Water content distribution (%)

(VG_WG80g) result

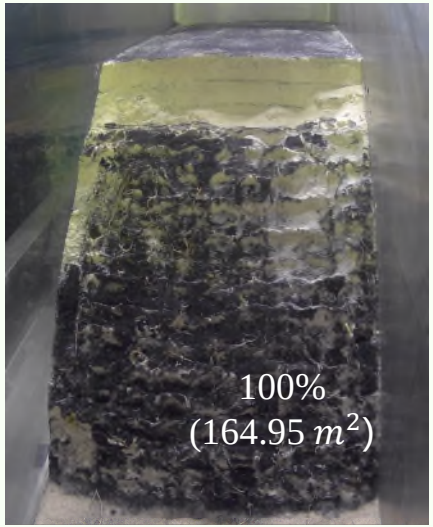
試驗結果 – 側根系植被邊坡

側根 (Lateral root)





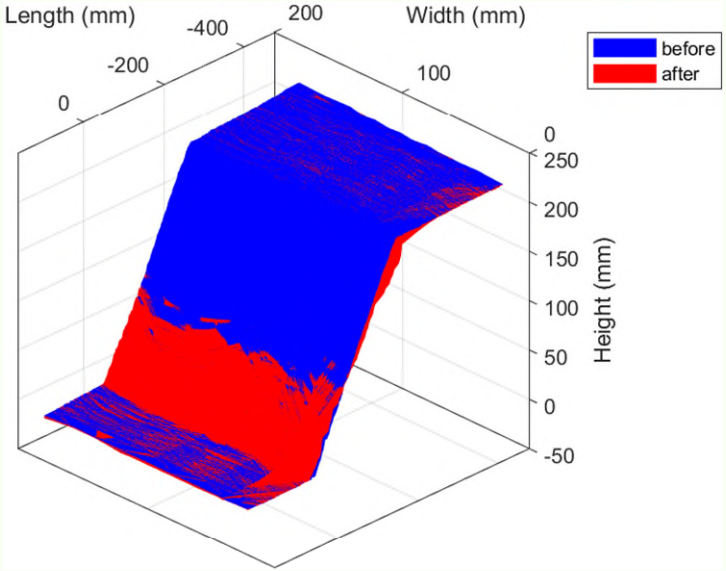
1g



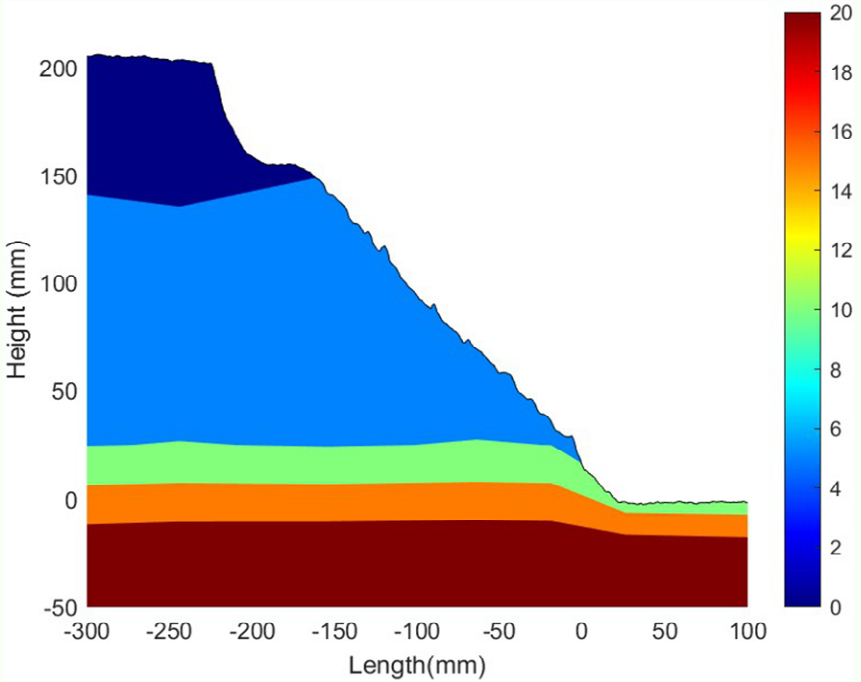
54g

(VG_RB54g) result

試驗結果 – 側根系植被邊坡



Depletion (m^3)	Accumulation (m^3)
270.22	64.46



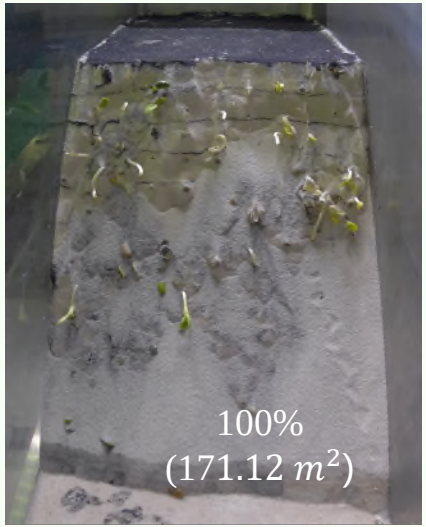
Water content distribution (%)

(VG_RB54g) result

試驗結果 – 主根系植被邊坡



1g



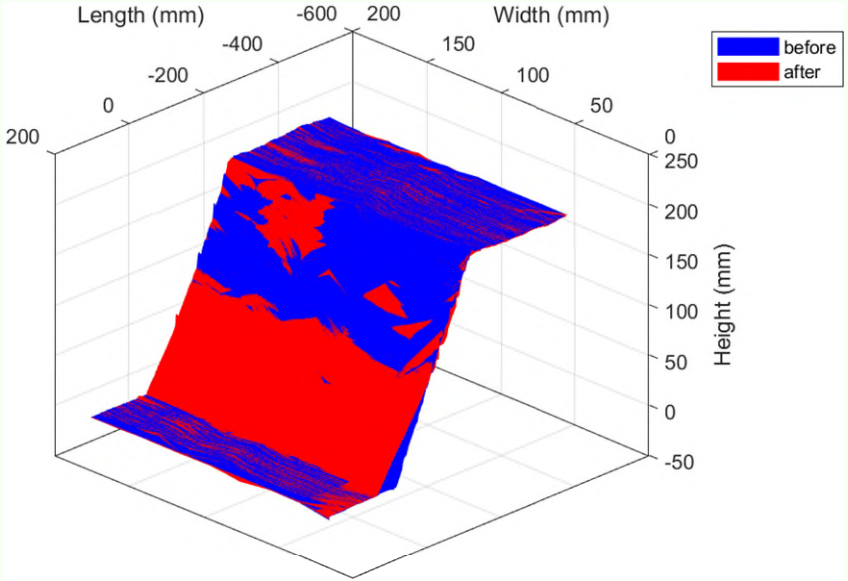
55g

主根及毛狀次生根
(Single taproot and hairy secondary root)

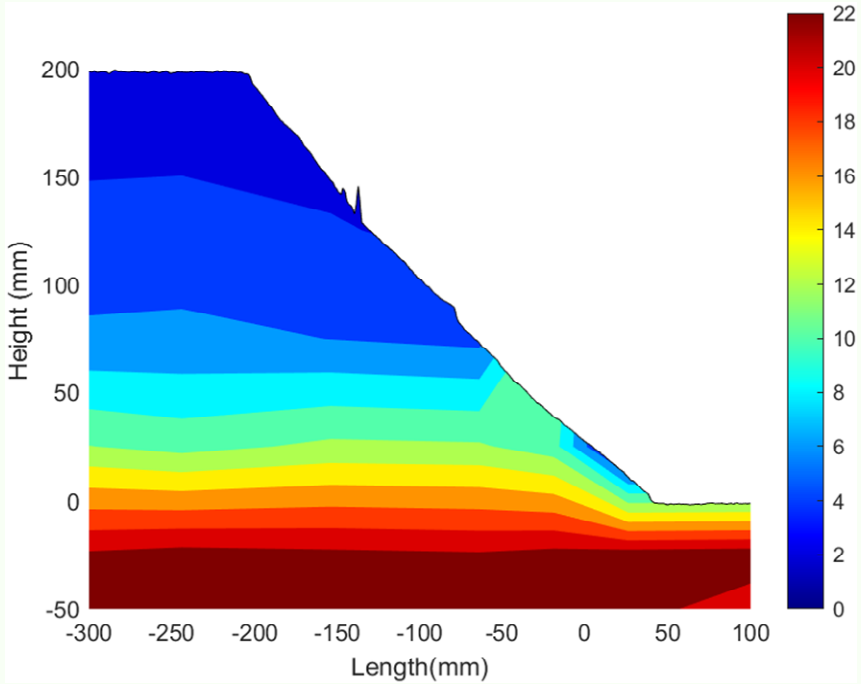


(VG_SF55g) result

試驗結果 – 主根系植被邊坡



Depletion (m^3)	Accumulation (m^3)
61.22	195.76



Water content distribution (%)

(VG_SF55g) result

05

結論

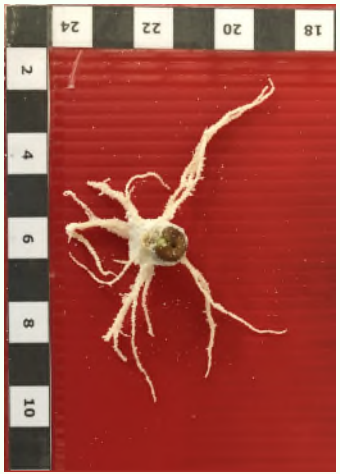


結論

試驗結果顯示，土壤中的根系會提升土壤凝聚力與摩擦角等抗剪強度，且與土壤邊坡做比較，植入小麥草、紅豆、向日葵根系的邊坡的安全係數為1.8、1.2與1.2，且能有效地避免邊坡產生淺層破壞，提高邊坡的穩定性。



鬚根
Fibrous root



側根
Horizontal lateral root



主根及毛狀次生根
Taproot and hairy secondary root


Thank you for
your kindly
attention!