公路土壤邊坡滑動無線感測網路監測系統研發

Development of wireless monitoring modules for soil slope failures of highway

主管單位：交通部運輸研究所港灣技術研究中心　計畫主持人：朱金元、謝明志、陳志芳

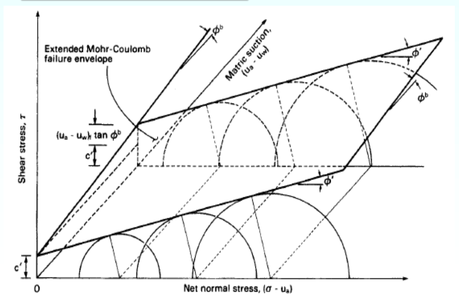
合作單位：財團法人成大研究發展基金會　計畫主持人：張文忠、黃安斌

整體目標 Overall objective

本計畫針對公路土壤邊坡可能遭遇之土層滑動破壞，進行解析法分析並搭配無線土層反應監測模組，測試發展適用於土層之解析法依時預警模式，用以互補現有以雨量監測為指標之經驗法預警模式，提高預警之準確與時效性。

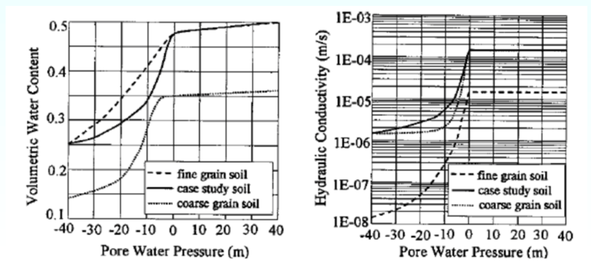
To improve the limitations of rainfall-based slope warning system, a new framework that integrated the hydro-mechanical slope analysis and wireless sensing modules for field key properties is under development. The target failure modes in this study include both surficial failures due to reduction of matrix suction and deep slips with failure surfaces in the saturated zone and triggerred by increasing of pore pressure. The long-term goal is to establish a customized, time-dependent warning system for highway slope failures triggered by rainfalls..

水力力學耦合邊坡穩定分析 Coupled hydro-mechanical slope stability analysis



$$\tau_{ff} = \left[c' + (u_a - u_w)\tan\varphi^b\right] + (\sigma - u_a)\tan\varphi'$$

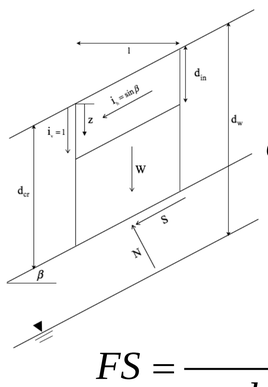
非飽和土壤剪力強度
Unsaturated shear strength



$$\frac{\partial}{\partial x}\left[k(h_p)\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[k(h_p)\frac{\partial h}{\partial y}\right] + \frac{\partial}{\partial z}\left[k(h_p)\frac{\partial h}{\partial z}\right] = \frac{\partial \theta(h_p)}{\partial x}$$

非飽和土層入滲/滲流分析
Unsaturated infiltration/seepage

邊坡之水力力學耦合穩定分析
Coupled hydro-mechanical stability analysis



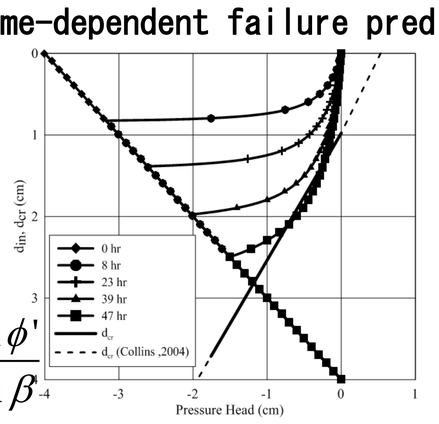
淺層臨界滑動深度 d_{cr}
(Critical depth, dcr)

$$d_{cr} = \frac{c' + \gamma_w \cdot h_c(z)\tan\phi^b}{\gamma_t \cdot \cos^2\beta(\tan\beta - \tan\phi')}$$

深層滑動安全係數
(FS of deep-seated slide)

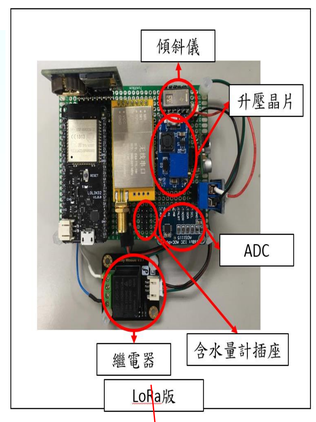
$$FS = \frac{c'}{\gamma_{sat} d_{cr}\sin\beta\cos\beta} + \left(\frac{\gamma_{sat} - \gamma_w r_u}{\gamma_{sat}}\right)\frac{\tan\phi'}{\tan\beta}$$

依時性無限邊坡破壞預測模式
Time-dependent failure prediction



土層無線監測模組 Slope wireless sensing modulus

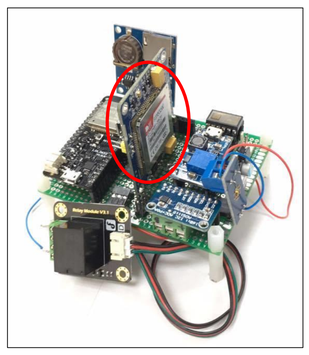
太陽能供電模組
(Solar power module)



高精度傾斜儀
(inclinometer)

液位計
(Liquid level meter)

土層無線監測模組
(Wireless sensing modulus)

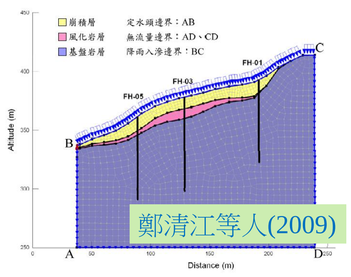


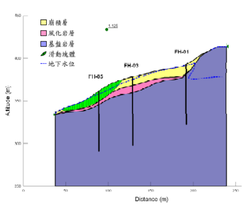
3G網路版本
(3G Gateway)

電容含水量計
(Capacitance moisture probe)

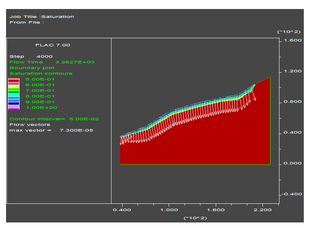
研究成果 Current progress

二維水力力學耦合邊坡分析
2D hydro-mechanical slope stability analysis

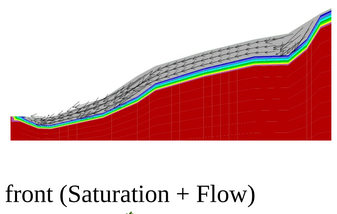


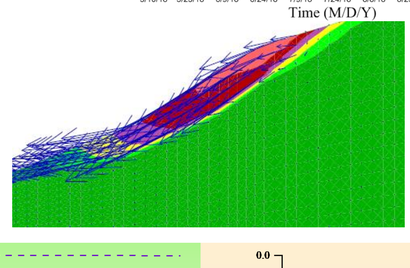


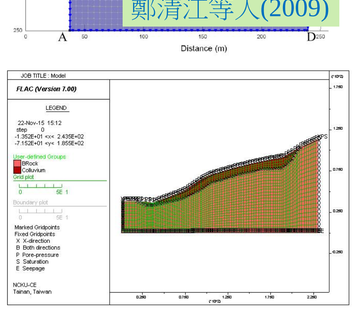
(b) 莫拉克颱風穩定性分析成果
(F.S.=1.125)

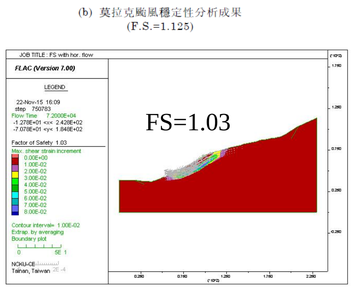


Wetting front (Saturation + Flow)

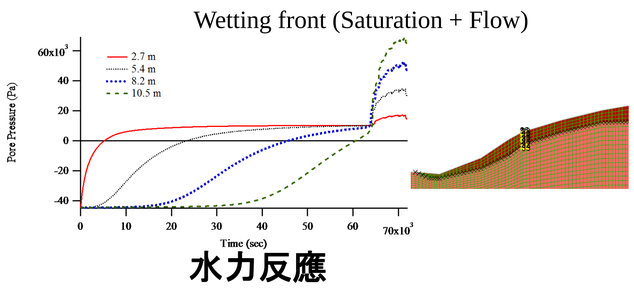




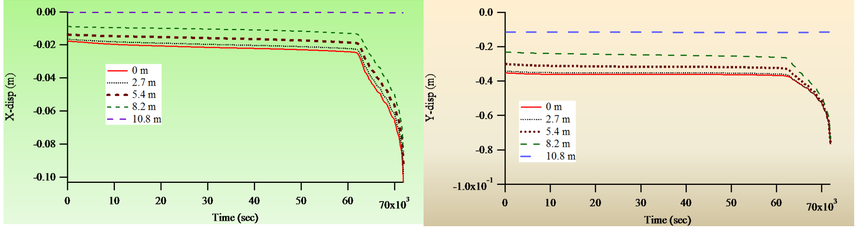




極限平衡分析比較
(Limit equilibrium analysis)

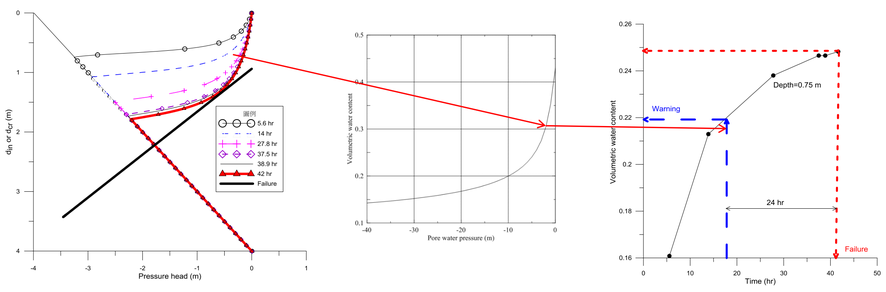


水力反應
(Hydraulic response)



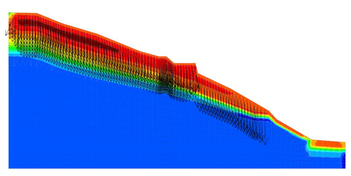
地表土層運動反應
(Surface motion response)

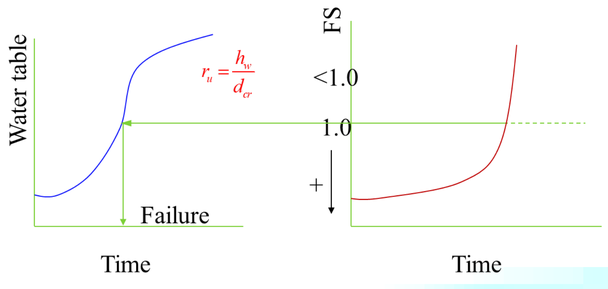
依時預警模式 (Time-dependent warning system)



無限邊坡淺層滑動含水量預警
(water-content-based warning)

$$FS = \frac{c'}{\gamma_{sat} d_{cr}\sin\beta\cos\beta} + \left(\frac{\gamma_{sat} - \gamma_w r_u}{\gamma_{sat}}\right)\frac{\tan\phi'}{\tan\beta}$$





飽和土層滑動地下水位預警架構
(Pore pressure-based deep slip warning)