ESTIMATING ADDITIONAL ROOT COHESION BY EXPLOITING A ROOT TOPOLOGICAL MODEL BASED ON LEONARDO'S RULE

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NH3.4

Chat time: 07 May, 16:15–18:00

Motivations

- Slope stabilization by plants is mainly controlled by the **biotechnical characteristics** of the root system and the roots-soil interaction

- Root structure can be represented through **root topological models,** i.e. schematic representations based on a defined topology graph theory

Biotechnical characteristics

- Root length
- Root density/area
- Root diameter profile
- Total number of roots
- Tensile strength

From Preti e Giadrossich (2009)

Landslide and vegetation in Rio Mameyes Basin (Puerto Rico)

Motivations

- Describing adequately the root architecture maybe helpful to answer to the following **questions**:
  - Which root architecture does guarantee a certain additional root reinforcement?
  - Which is the most suitable plant species to be adopted in certain soil or water availability conditions?

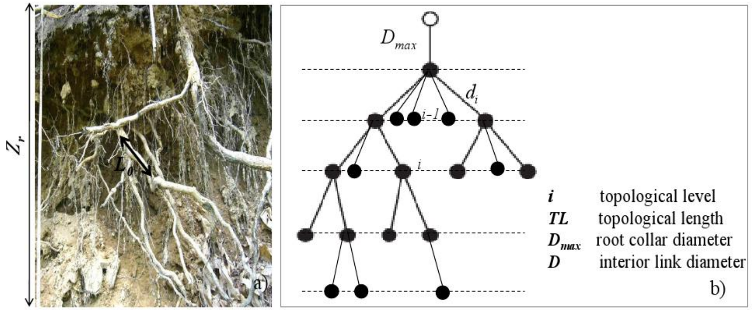
Objectives

- Exploiting a **modeling framework** for estimating the additional root cohesion in different configuration of root architectures, assumed as representative of different static **plant-growth conditions**
- Assessing the ultimate effects on **slope stability** of a synthetic slope

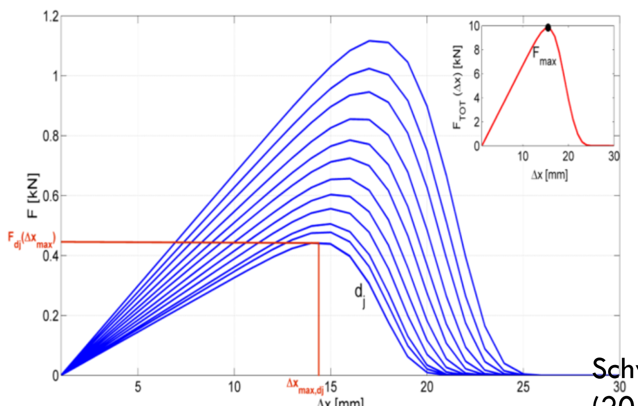
Modeling framework

Arnone et al., 2016 (WRR)

Topological Model

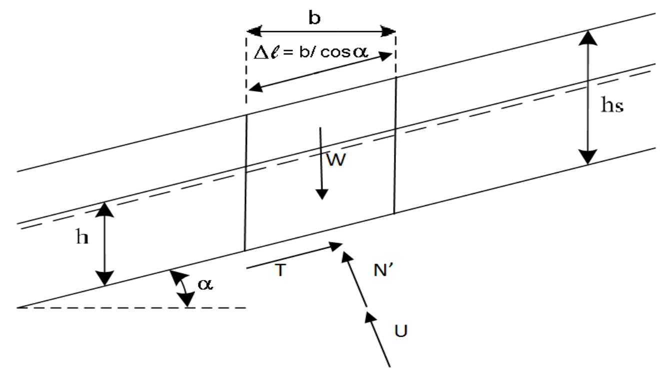


Root Bundle Model



Schwarz et al., (2013, HESS)

Stability model: Infinite slope



$$FS_{tot} = \Delta FS_r + FS_s = \overbrace{\frac{c_r}{\gamma_t(\theta) z_n \sin\omega}}^{\text{Root Cohesion Term}} + FS_s$$

Additional FS due to root reinforcement

Topological model

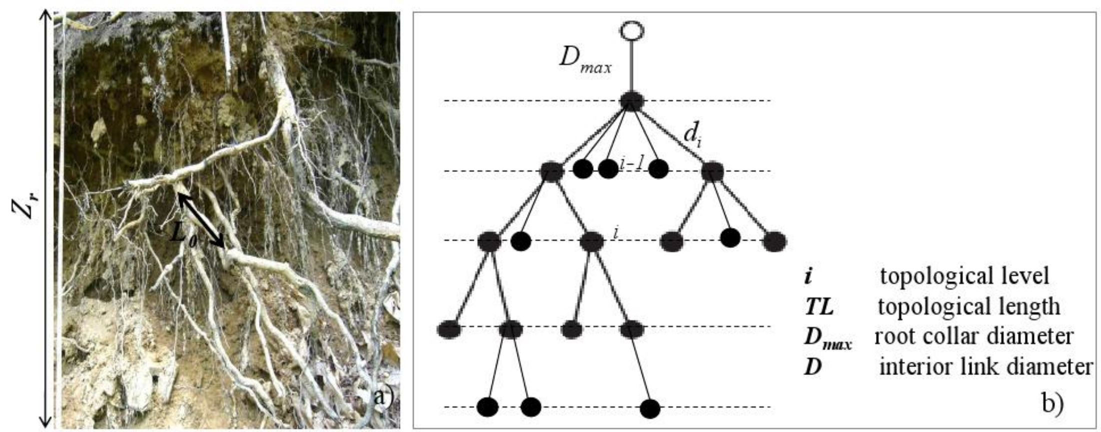
LEONARDO'S RULE: The cross-sectional area of a branch of a tree is equal to the sum of the cross-sectional areas of the branches at any higher level (Oppelt et al., 2001)

$$\alpha_d \cdot N_i \cdot d_i^2 = N_{i-1} \cdot d_{i-1}^2$$

$$d_i = d_{i-1}\sqrt{\frac{1}{\alpha_d} \cdot \frac{N_{i-1}}{N_i}}$$

$$AR_i = \frac{\pi}{4} \cdot \frac{d_{i-1}}{\alpha_d} N_{i-1}$$

$$N_i = f(i|r,p) \cdot N_{tot}.$$



α_d and D_{max} are the calibration parameters (by means of measured data of AR)

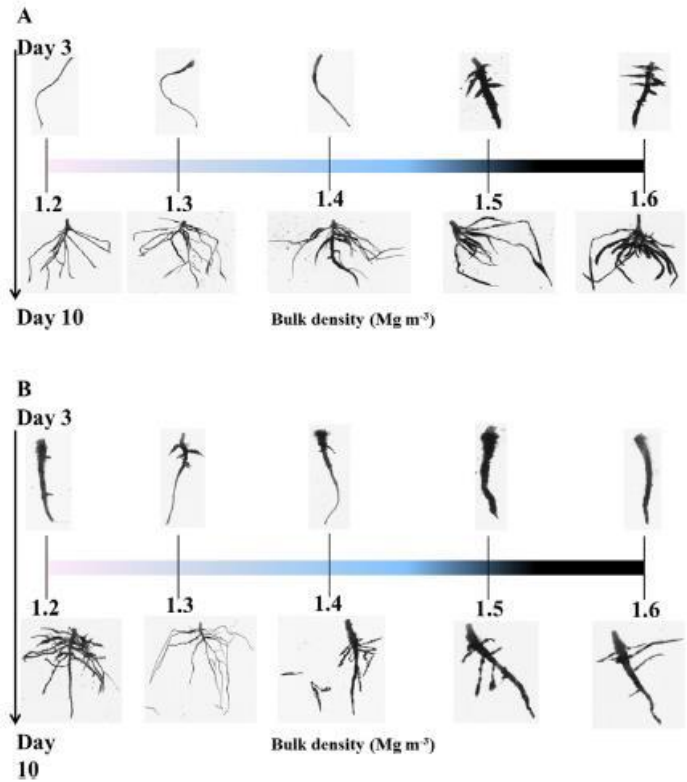
TL , total root length (RL) and N_{tot} are the required input parameters

Root system development

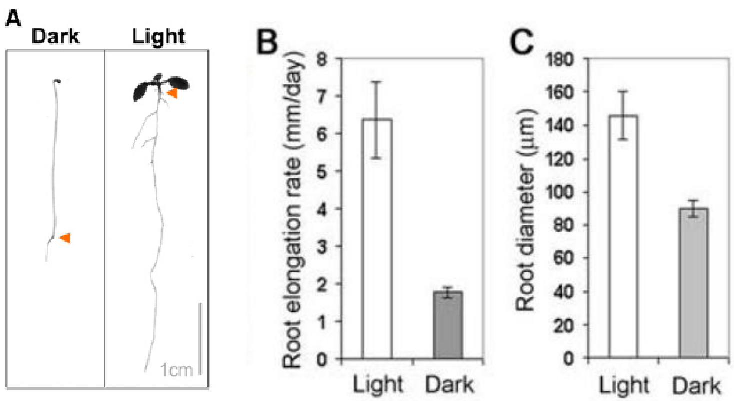
Controlling factors

- Exposure to light
- Water availability
- Nutrient availability
- Soil effects (i.e., compaction, mechanical stress, topography, …)

Tracy et al., 2013



Laxmi et al. 2008



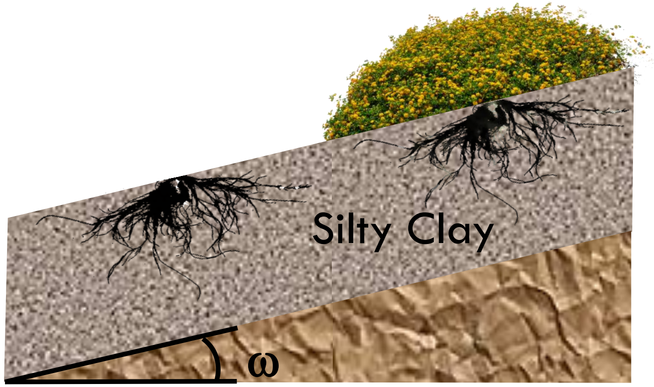
Case study: reference data

Arnone et al., 2016 (WRR)

Reference Scheme

In Situ DATA		
Depth	N_{roots}	A_r obs
m	-	cm^2
0.00	1	2.8
0.05	16	
0.10	25	1.8
0.15	21	1.4
0.20	12	1.55
0.25	12	1.2
0.30	8	1.3
0.35	6	0.5
0.40	5	0.45
0.45	3	0.4
0.50	3	0.47
0.55	2	0.2
0.60	2	
0.65	1	
0.70	0	

Spartium Junceum (Spanish broom).
From Preti e Giadrossich, 2009



Biotechnical properties[a]					
α	β	A_0	E_0	RL	N_{tot}
[-]	[-]	[MPa/mm]	[MPa/mm]	[cm]	[-]
-0.306	-0.826	37.605	649	70	117

Soil Parameters				
φ'	c'	γ	γ_w	ω
[°]	[kPa]	[kN/m^3]	[kN/m^3]	[°]
20	0	20	9.81	26.5

[a] Parameters α-A_0 and β-E_0 are respectively are exponents and coefficients of the power laws that describe tensile strength and Young's modulus of the roots, and RL is the root length. From [14,15]

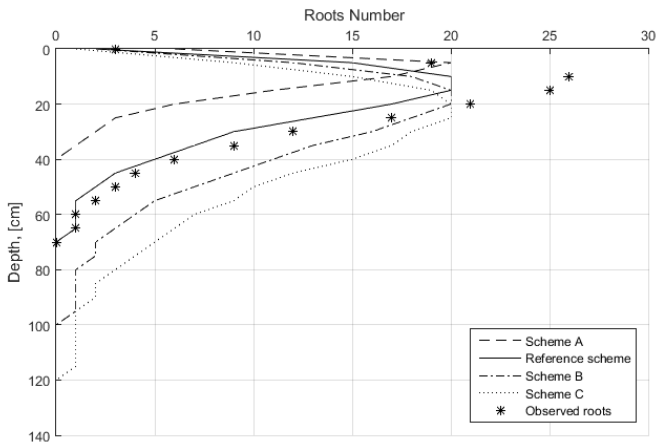
Case study: model configurations

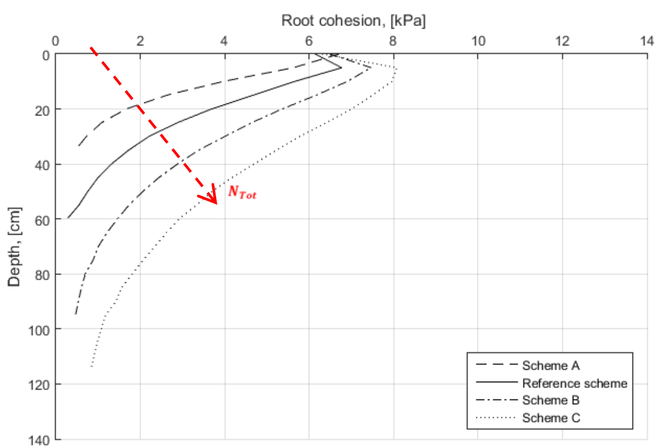
	Exposure to light	Soil Compaction	Water availability	Nutrient availability
Reference Scheme	normal	normal	normal	normal
Scheme A	normal	**HIGH**	normal	normal
Scheme B	**HIGH**	normale	**HIGH**	normale
Scheme C	**HIGH**	normale	**HIGH**	**HIGH**

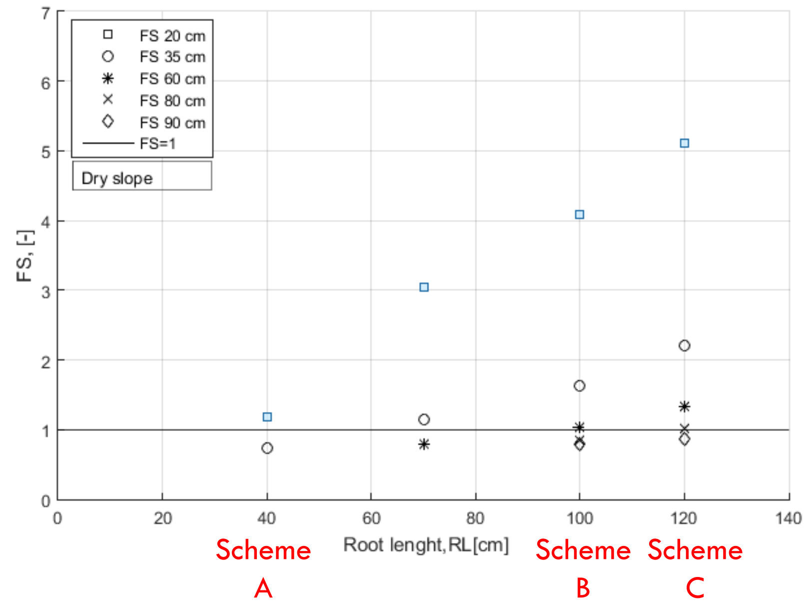
	Root Lenght (RL) [cm]	N_{tot}
Reference Scheme	70	117
Scheme A	40	67
Scheme B	100	167
Scheme C	120	200

$$\frac{RL}{N_{tot}} = cost$$

Case study: results







Ielapi et al., (2019) *Copyright © 2019, IEEE*

Concluding remarks

- The ultimate effects of additional root reinforcement on slope stability depend on the slope conditions and the location of the hypothetical failure plane

- The effective utility of the plant reinforcement depends on its <u>root length</u>, compared with the position of the depth of failure. <u>A root length simply greater than the failure depth might be not sufficient</u> to improve the stability of the slope

- Results are useful for identifying the depth of the failure surface, beyond which the root reinforcement is not sufficient to avoid shallow landslide

- The use of the presented coupled modeling framework can be helpful in planning phase, for assessing whether the plant-growth conditions would be favorable for the stabilizing scopes

Main References

Arnone E., D. Caracciolo, L. V. Noto, F. Preti, and R. L. Bras (2016) Modeling the hydrological and mechanical effect of roots on shallow landslides. Water Resources Research, 52 (11), 8590-8612

Ielapi F., E. Arnone and Q. Napoleoni, (2019)Assessing root reinforcement for slope stabilization under different plant-growth conditions," 2019 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Portici, Italy, pp. 116-120.

Laxmi A., J. Pan, M. Morsy, R. Chen (2008), Light plays an essential role in intracellular distribution of auxin efflux carrier PIN2 in *Arabidopsis thaliana*, PLoS ONE 3:e1510

Mattia C., G.B. Bischetti, G. Gentile (2005). Biotechnical Characteristics of Root Systems of Typical Mediterranean Species. Plant and Soil, 278, 23-32

Preti F. and F. Giadrossich (2009) Root reinforcement and slope bioengineering stabilization by Spanish Broom (Spartium junceum L.). Hydrol. Earth Syst. Sci., 13 (09), 713–1726

Schwarz M., F. Giadrossich, and D. Cohen (2013) Modeling root reinforcement using a root-failureWeibull survival function. Hydrol. Earth Syst. Sci., 17 (13), 4367–4377

Tracy S.R., C. R. Black, J. A. Roberts, S. J. Mooney (2013) Exploring the interacting effect of soil texture and bulk density on root system development in tomato (Solanum lycopersicum L.), Environmental and Experimental Botany, 91, 38-47.