

A multivariate database for root-induced mechanical reinforcement: status of work and initial insights

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ABSTRACT: This paper provides an initial insight into a quantitative database of root-induced effective cohesion currently under development. The database relies on an extensive review of technical literature focusing on depth-wise trends of cohesion, root distribution, and root density. To potentially allow the implementation of advanced data-driven approaches, the database incorporates, where available, a large set of variables including the number, age, and size of the plant species examined, as well as soil and climate information. The paper describes the current structure of the work-in-progress database and discusses its potential developments and utilization for future data-driven analyses relying on multivariate statistical, probabilistic, and/or machine learning approaches among others. Although at an early stage, the dataset and the insights derived from it serve as a valuable resource for researchers aiming to enhance understanding of the resistance increase in rooted soils.

Keywords: Soil-root systems; geotechnical design; data-driven approaches; multivariate database; root-induced soil strength

1 INTRODUCTION

As society becomes increasingly aware of environmental concerns and of the detrimental effects of human activities on ecosystems, Soil and Water Bio-engineering (SWBe) methods, such as slope stabilization utilizing vegetation, are progressively emerging within the field of geotechnical engineering. The role of roots in the modification of the shear strength of soils has been extensively investigated by diverse disciplines including forest science and geotechnical engineering among others. These studies have parameterized the contribution of root systems to soil strength through an increase in the value of the friction angle or, more frequently, effective cohesion.

Geotechnical engineering design codes are progressively shifting towards non-deterministic formats such as the LRFD used in the current version of Eurocode 7 and full-probabilistic techniques, whose use will be explicitly allowed in the revision of the same code. The development of non-deterministic (and code-compliant) geotechnical approaches to the quantitative modelling of root-soil interaction would require data-driven analyses and would thus benefit from the expansion of existing databases containing experimental measurement of root-induced reinforcement. However, to the best of the authors' knowledge, studies have often been limited to specific sites characterized by specific climatic and pedomorphological features, plant species, and so forth.

This paper provides an initial insight into a quantitative database of root-induced effective cohesion which is currently under development. The database relies on an extensive review of technical literature focusing on depth-wise trends of cohesion, root distribution, and root density. To allow the implementation of advanced data-driven approaches in perspective, the database incorporates, where available, an extended set of variables including the number, age, and size of the plant species examined, as well as soil and climate information. The paper describes the current structure of the work-in-progress database.

2 MATERIAL AND METHODS

To date, the database contains findings from 20 scientific studies (Endo & Tsuruta 1969, Abe & Iwamoto 1986, Abernethy & Rutherford 2001, Simon & Collison 2002, Bischetti et al. 2005, De Baets et al. 2008, Abdi et al. 2010, Comino & Marengo 2010, Burylo et al. 2011, Ji et al. 2012, Bassanelli et al. 2013, Naghdi et al. 2013, Abdi 2014, Ghestem et al. 2014, Leung et al. 2015, Chiaradia et al. 2016, Federica et al. 2017, Ettbeb et al. 2020, Meng & Yang 2020, Draebing et al. 2022). Further details can be obtained in tabular form in Geppetti et al. (2025). The information includes the geographical location and case- and site-specific climatic conditions in terms of average annual rainfall of the case study, soil texture, plant species age and/or diameter of the stem, number and



Figure 1. Numerosity and geographical distribution of experimental sites

type of experimental tests performed to obtain root mechanical information, soil root induced cohesion (i.e. the additional cohesion quota offered by the roots) and information on root distribution, with depth and root tensile strength. Endo & Tsuruta (1969) and Abe & Iwamoto (1986) determine the apparent cohesion of the roots with full-scale direct shear tests, Ettbeb et al. (2020) with standard direct shear and tensile tests, Meng & Yang (2020) with standard triaxial tests and while the remaining authors estimate the value of cohesion through correlations based on the results of tensile tests and on the root area ratio (RAR) of the root system. In the analyzed works, root cohesion is estimated using both the W&W models (Wu 1976, Waldron 1977 and Preti 2006) and Fiber Bundle Models (FBM) (Daniels 1945, Pollen and Simon 2005, Hidalgo et al., 2001 and Schwarz et al. 2010) as further detailed in Geppetti et al. (2025).

3 SELECTED WORK-IN-PROGRESS CONTENTS

From the analysis conducted on the 20 scientific works dealing with the resistance of root soils it was possible to deduce that the investigated sites are distributed more or less throughout the planet with a greater concentration in Europe and a greater shortage in the American continent (Figure 1).

Of the 69 species investigated, the majority (28, corresponding to approximately 40% of the total set) are trees, followed by shrubs (22, corresponding to $\approx 32\%$) and finally by herbs (19, corresponding to $\approx 28\%$). Among these, the most present species is *Picea abies* (present in 4 articles) followed by *Fagus sylvatica* (present in 3 articles) and by *Tamarix canariensis* and *Castanea sativa* (both present in two articles). Out of 4060 experimental tests, the largest number (3981) is represented by root tensile tests followed by 65 direct shear and 14 triaxial tests. Plant ages vary from a minimum of 2 months *P. polystachion* *P. pedicellatum* (Ettbeb et al. 2020) to a maximum of 40 years for a *Castanea sativa* (Bassanelli et al. 2013). Figure 2 shows the density (expressed as a percentage) of experimental RAR data with depth.

From the analysis of Figure 2 it is possible to deduce that in the various measurement campaigns conducted, RAR values between 0.2 and 0.3% were mainly determined in the first metre of investigated soil. Similarly, Figure 3 reports the density of data of apparent root cohesion with depth. Observation of Figure 3 allows us to conclude that the cohesion values most present in the dataset range close to 30 kPa for the first 50 cm of depth. Most of the investigated works report the minimum, maximum and average values of diameter and tensile strength obtained from the investigated root samples. This information in terms of

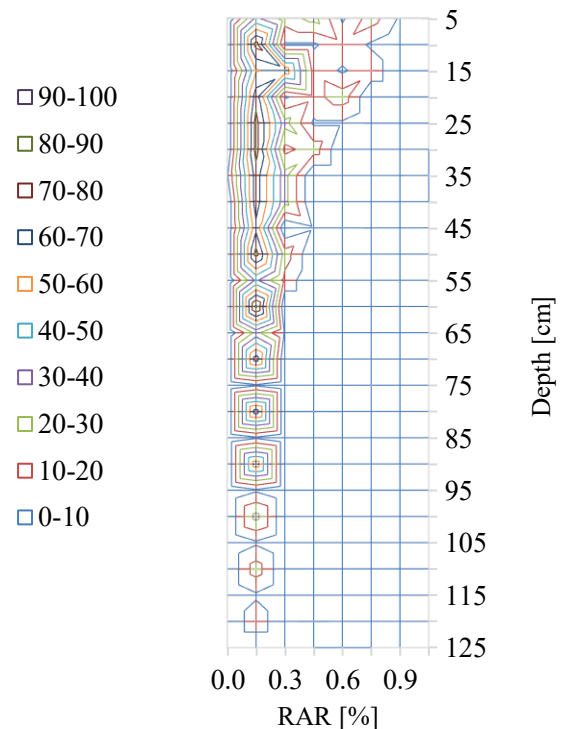


Figure 2. RAR data density with depth

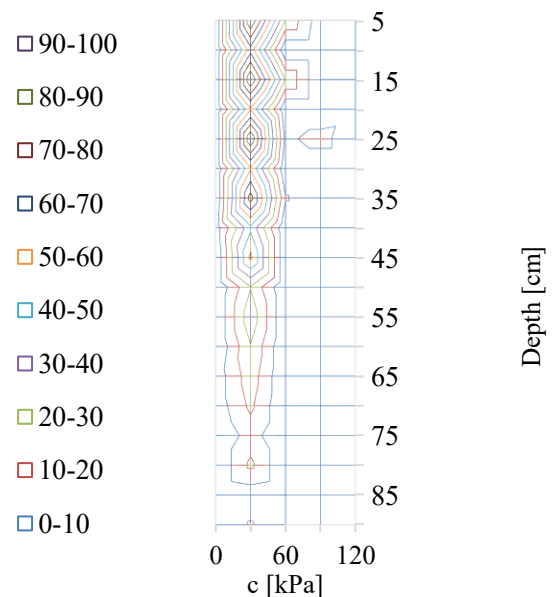


Figure 3. Root cohesion data density with depth

frequency distribution is reported in Figures 4 and 5 respectively. From Figure 4 it is possible to note that the minimum values of the root diameter are around 0.7 mm, the average values between 1.3 and 2.6 mm while the maximum values cover more or less the entire spectrum with peaks between 5.1 and 6.4 mm.

With respect to the tensile strength of the roots (Figure 5), most of the minimum values range around 25 MPa, the average values are concentrated between 25.1 and 78.3 MPa while the maximum values are distributed more uniformly with a peak around 78.3 MPa.

4 CONCLUDING REMARKS

This work proposes the creation of a database containing information regarding the strengthening of rooted soils through the analysis of scientific studies. The work is under development and information extracted so far from 20 articles is summarized and commented briefly. The availability of a multivariate, quantitative database would prove beneficial at least for: (1) advancing academic research on the subject; (2) allowing the development of code-compliant geotechnical design methods for Soil Water Bioengineering (SWBe) solutions; and (3) providing a well-structured source for data-driven analyses relying on multivariate statistical, probabilistic, and/or machine learning approaches among others.

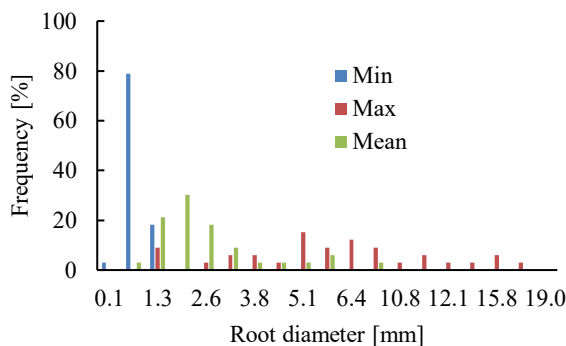


Figure 4. Min, max and mean root diameter frequency distribution

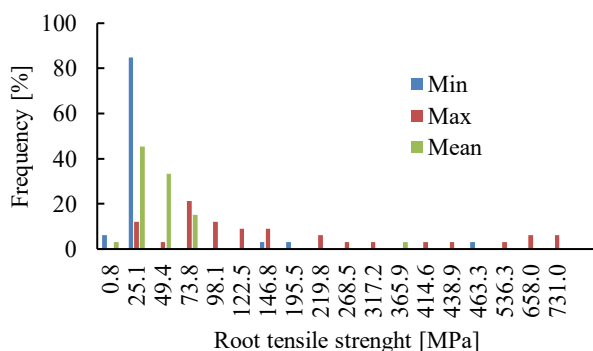


Figure 5. Min, max and mean root tensile strength frequency distribution

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