Teaching soil mechanics core concepts: mapping the structure of university textbooks worldwide

M. Calvello

University of Salerno, Fisciano (SA), Italy
mcalvello@unisa.it

ABSTRACT: Textbooks serve as essential reference materials for educators, structured to introduce concepts in a logical sequence. This study explores how soil mechanics concepts are treated in university textbooks, by analysing the Table of Contents (TOCs) of introductory soil mechanics and geotechnical engineering books. The research begins with the compilation of a list of these textbooks—sourced from personal knowledge, colleague recommendations, and bibliographic reviews—followed by an initial discussion on terminology and the presentation of key features of: landmark textbooks, latest editions of widely adopted textbooks written in English, textbooks written in other languages. A comparative analysis of the considered textbooks is then conducted by considering the topics addressed and their sequence of presentation. The main outputs of the analysis revolve around the original definition and clustering of soil mechanics key topics and core concepts. The findings aim to inform educators about similarities and differences in topic coverage and sequencing within introductory soil mechanics and geotechnical engineering textbooks written across different time periods and languages.

Keywords: Textbooks, Soil mechanics, Comparative analysis

1 Introduction

Textbooks are, in many cases, the primary reference material in the educational framework of a university course. These books are authored by instructors who often have significant experience in teaching and research. The structure of textbooks is designed to introduce fundamental concepts in a logical sequence, beginning with foundational principles before advancing to more complex topics. The Table of Contents (TOC) of textbooks can thus be considered a sort of roadmap for teaching to students the main concepts of a course or discipline, as it implicitly highlights a set of concepts' categories and a defined sequence for teaching and learning them. Numerous textbooks are used throughout the world in core university courses in soil mechanics and geotechnical engineering. This study aims to explore how soil mechanics concepts are treated in these textbooks. This study will also provide a (relatively long) list of soil mechanics textbooks that, as a compiled and commented list of references, may be useful for geotechnical educators worldwide wishing to expand their teaching material.

2 Compiling the list of textbooks

The author has looked for books that can be considered introductory soil mechanics textbooks. The books of interest are the ones that have been used or could be used, in total or in a significant part, within undergraduate courses introducing soil mechanics topics to undergraduate civil engineering students for the first time. Therefore, books of interest include textbooks that discuss geotechnical engineering applications after an in-depth presentation of soil mechanics fundamental concepts, but do not include geotechnical engineering textbooks that assume that a thorough knowledge of soil mechanics fundamental concepts must be acquired using other reference material (e.g., books

organized in sequence). The adopted list of books has been compiled from different sources: personal knowledge, valuable recommendations from colleagues, and a bibliographic review.

Recommendations from colleagues were mainly used for discovering textbooks adopted where English is not the mother tongue and to get information on books written in English widely adopted globally. To this end, besides personal contacts with a few colleagues, an email survey was conducted involving the members of the ISSMGE Technical Committee 306 “Geo-engineering education”. Three questions were asked. What book do you, or your colleagues, use in your University to teach the first 'Soil mechanics' course? What are the books (or the book) most widely used in your country? Could you send me the links to TOCs of such books or a file with the TOCs? 22 useful replies were received and, interacting with the respondents, many relevant comments and TOCs were collected. For text and TOCs received in languages not spoken by the author, automatic translation tools were used to translate them into English. The survey carried out cannot be considered in any way comprehensive, as many languages (and countries) are missing from the list. Moreover, it must be noted that in some countries (e.g., Spain, Brazil) using lecture notes produced locally by University professors, instead of published books, is still a widespread practice. For such cases, the analysis of syllabi would be more appropriate to understand how soil mechanics and geotechnical engineering concepts are introduced to undergraduate students, yet this goes beyond the scope of this study. The search for books written in English was also conducted browsing the web, library catalogues and using these repositories: Perlego (https://www.perlego.com/), Google books (https://books.google.com/), the Internet Archive (https://archive.org/). The main keywords adopted were soil mechanics, geotechnical engineering and geotechnics.

3 Textbooks

3.1 Analysed textbooks and terminology

Tables 1 and 2 show an overview of the analysed textbooks, respectively for the 24 books written in English and for the 18 books written in languages other than English. The tables report the year of publication of the last edition of each textbook even when the tables of contents of previous editions may have been considered in this work. The ID includes the authors’ initials and the year of publication, for the books not written in English two initial capital letters are also used.

Most of the 42 books analysed herein use the words “soil mechanics” (30 books) in their title, in a few cases together with the words “foundations” (*Bu2011, So1979, CR-N1981, SP-M2007*) or “applications” (*Po2014*). 11 books adopt the words “geotechnics” or “geotechnical engineering”, and the remaining book is called *Fundamentals of ground engineering* (*At2014*). One may expect that the different titles may also give an indication on how much the textbook is devoted to introducing, essentially, the fundamental concepts of soil mechanics or, alternatively, to give significant space to geotechnical applications. Such a correlation is lacking or not evident. For instance, very popular English books like *Smith’s elements of soil mechanics* (*Sm2021*) or *Craig's soil mechanics* (*KC2019*), whose latest editions are the 10th and the 9th respectively, devote a large numbers of chapters to geotechnical applications while, at the other end of the spectrum, the two Italian books called *Geotechnics* (*IT-L2012*) and *Principles of geotechnics* (*IT-B2021*) and the French book *Theory and practice of geotechnics* (*FR-P2013*) only devote the last two final chapters to applications.

It is worth noting that Atkinson promotes the use of the phrase “ground engineering” encompassing both soil mechanics and geotechnical engineering, which have therefore, in this case, a clearly different and complementary meaning. Indeed, in his book *Fundamentals of ground engineering* (*At2014*) the chapters are grouped in four sections: i) discovering the ground; ii) essential physics and mechanics; iii) soil mechanics; iv) geotechnical engineering. Often used in the titles, to highlight the fact that these textbooks are introductory books for the subject, are the words “fundamentals” (5 times), “principles” (5 times), “elements” (3 times), “introduction to” (3 times) and “basic” (3 times). These words are essentially used as synonyms, as no distinct meanings have been identified. No clear trends have emerged regarding the authors' country of origin, the language used, or the year of publication. In essence, all the terminology choices made by the authors of the analysed textbooks appear to be driven by individual preferences.

Table 1. Analysed textbooks written in English

ID	Authors	Ed*	Year	Title
AB1978	Atkinson, Bransby	1	1978	The mechanics of soils: an introduction to critical state soil mechanics
At2007	Atkinson	2	2007	The mechanics of soils and foundations
At2014	Atkinson	1	2014	Fundamentals of ground engineering
Ba2016	Barnes	4	2016	Soil mechanics: principles and practice
Br2023	Briaud	2	2023	Geotechnical engineering: unsaturated and saturated soils
Bu2011	Budhu	3	2011	Soil mechanics and foundations
Bu2015	Budhu	1	2015	Soil mechanics fundamentals
CYK2010	Coduto, Yeung, Kitch	2	2010	Geotechnical engineering: principles & practices
Da1979	Das	1	1979	Introduction to soil mechanics
Da2021	Das	10	2021	Principles of geotechnical engineering
DS2016	Das, Sivakugan	5	2016	Fundamentals of geotechnical engineering
HKS2023	Holtz, Kovacs, Sheahan	3	2023	An introduction to geotechnical engineering
KC2019	Knappet, Craig	9	2019	Craig's soil mechanics
La2008	Lancellotta	2	2008	Geotechnical engineering
LW1969	Lambe, Withman	1	1969	Soil mechanics
Mu2009	Muir Wood	1	2009	Soil mechanics: a one-dimensional introduction
No2013	Nova	1	2013	Soil mechanics
Or1995	Ortigao	1	1995	Soil mechanics in the light of critical state theories
Po2014	Powrie	3	2014	Soil mechanics: concepts and applications
Sm2021	Smith	10	2021	Smith's elements of soil mechanics
So1979	Sowers	4	1979	Introductory soil mechanics and foundations
Ta1948	Taylor	1	1948	Fundamentals of soil mechanics
TPM1996	Terzaghi, Peck, Mesri	3	1996	Soil mechanics in engineering practice
We2009	Wesley	1	2009	Fundamentals of soil mechanics for sedimentary and residual soils

* Last published edition (hyperlink to main web reference, i.e., editor's page when available)

Table 2. Analysed textbooks written in languages other than English

ID	Authors	Ed*	Year	Language	Title (English translation)
AR-A2019	Al-Qasabi	1	2019	Arabic	Soil mechanics
CH-G2022	Li, Zhang, Yu	3	2022	Chinese	Soil mechanics
CH-L2020	Liu	5	2020	Chinese	Soil mechanics
CR-N1981	Nonveiller	1	1981	Croatian	Soil mechanics and foundation
DA-O2012	Ovesen	2	2012	Danish	Textbook in geotechnics
FR-P2013	Plumelle et al.	1	2013	French	Theory and practice of geotechnics
FR-S1997	Schlosser	2	1997	French	Elements of soil mechanics
GR-K2016	Kavvadas	2	2016	Greek	Elements of soil mechanics
IT-B2021	Berardi	4	2021	Italian	Principles of geotechnics
IT-B2018	Burghignoli	1	2018	Italian	Soil mechanics
IT-C2004	Colombo, Colleselli	3	2004	Italian	Elements of geotechnics
IT-L2012	Lancellotta	4	2012	Italian	Geotechnics
KO-L2021	Lee	3	2021	Korean	Principles of soil mechanics
PO-D2006	De Sousa Pinto	3	2006	Portuguese	Basic soil mechanics course
PO-M2024	Matos Fernandes	6	2024	Portuguese	Soil mechanics: concepts and basic principles
SP-M2007	Muzas Labad	1	2007	Spanish	Soil mechanics and foundations
TU-K1999	Kumbasar, Kip	1	1999	Turkish	Soil mechanics problems
TU-U2020	Uzuner	11	2020	Turkish	Basic soil mechanics with solved problems

* Last published edition (hyperlink to web reference in original language, when available)

3.2 Landmark textbooks written in English

One of the first published textbooks is *Soil mechanics in engineering practice* by K. Terzaghi and R.B. Peck (1948). The 3rd and last edition (with co-author G. Mesri) dates 1996. The book is structured in three parts: A) Physical properties of soils, B) Theoretical soil mechanics, and C) Problems of design and construction. The structure of this book is clearly tied with an instructional purpose, expressed in the preface of the first edition as follows: '*[the first] two parts are very short, but they contain all that engineering students and the average engineer need to know about soil mechanics proper at the present time. The heart of the book is Part C. Part C deals with the art of getting satisfactory results in earthwork and foundation engineering at a reasonable cost, in spite of the complexity of the structure of natural soil strata and in spite of the inevitable gaps in our knowledge of the soil conditions.'* They continue by saying '*Therefore, the experienced engineer is advised to start reading the book at the beginning of this part. He should use Parts A and B only for reference, to get information about concepts with which he is not yet familiar.*' The text highlights two categories of envisioned readerships: (university) students and practising geotechnical engineers. Considering that from the first to the last edition almost 50 years elapsed, it is worth to highlight that the structure of the book has not changed and to report text written in 1996 by the (living) authors (i.e., Peck and Mesri): '*In the half-century since these words were written, research [..] has continued unabated [..] [part A] of this edition is essentially a digest of the findings of research workers concerning the properties of soil that are of interest to engineers. The digest presents the findings from a fundamental point of view rather than as representing any one school of thought. [..] on the other hand [part B] has been increased only slightly, because the essential theoretical tools were already available 50 years ago.*'

Not too different is the structure of the other "grandfather" of geotechnical engineering textbooks, *Fundamentals of soil mechanics* by D.W. Taylor (1948), who writes: '*Books of a number of types on this subject are needed [..] This book is written as a textbook for use in graduate courses, but it is presented in such form that by the omission of certain portions it can be used in undergraduate courses. Practising engineers and specialists in soil engineering may find the book of interest and value but, primarily, it is written for the student.*' The topics deemed fundamental for soil mechanics are presented by means of 20 chapters. Although the book does not explicitly assign the chapters to parts or sections, the following thematic grouping can be inferred: origin, physical properties and classification of soils; soil investigation; role of water in soils; consolidation; stresses and soil settlements; soil strength; geotechnical applications.

Very different is the structure of another "milestone textbook": *Soil mechanics* by T.W. Lambe and R.V. Whitman (1969), 10 years later also published in a SI edition. The preface of this book starts with the following almost-tautological statement: '*Soil mechanics is designed as a text for an introductory course in soil mechanics.'* Yet, the subsequent text masterfully states, in just one sentence, the gist of the textbook and its instructional purpose: '*An intense effort was made to identify the truly fundamental and relevant principles of soil mechanics and to present them clearly and thoroughly.*' This book has 34 chapters structured in five parts: I) Introduction; II) The nature of soil; III) Dry soil; IV) Soil with water – no flow or steady flow; V) Soil with water – transient flow. The key driver of the explanations is clearly the state of the soil in relation the absence or presence of water filling the void space. Concerning the main soil mechanics concepts addressed, the sequence of presentation in the three parts follows a similar structure. At first, stresses are presented: in the dry soil mass, introducing the principle of effective stress, and considering undrained loading and consolidation. Then, stress-strain relationships are discussed, in general and in relation to drained and undrained conditions. In each part, a chapter is also specifically devoted to shear strength considering: cohesionless soils, drained and undrained conditions. In part IV, seepage is also addressed.

Finally, a singular book worth mentioning in this section, even if it cannot be considered a textbook for introductory soil mechanics courses (and thus it was not included in Table 1), is *Fundamentals of soil behavior* (Mitchell and Soga, 2005), whose first edition was written by J.K. Mitchell in 1976 and was published in the same book series of Soil Mechanics (Lambe and Whitman, 1969). The book is herein cited because it can be considered, in my opinion, a key reference for all geotechnical instructors looking for teaching material aimed at developing '*an understanding of the factors determining and controlling the engineering properties of soils, with emphasis on the why aspect of soil behavior.*' To this aim, in the book, '*principles from chemistry, geology, material science and physics are introduced as necessary to develop background of the phenomena under study.*'

3.3 Widely-adopted recent textbooks written in English

The books written in English whose latest edition has been published from 2010 onwards are 13. Albeit the survey carried out cannot be considered exhaustive, and thus the information acquired is not statistically significant, the following two books have been frequently mentioned: *Craig's soil mechanics*, by J.K. Knappet and R.F. Craig (*KC2020*), and *Principles of geotechnical engineering*, by B.M. Das (*Da2021*). They are also among the books counting more published editions, respectively 9 and 10, which is a factor that can be considered a proxy for the diffusion of a textbook.

Craig's soil mechanics (9th ed., 2020) is a textbook that '*covers fundamental soil mechanics and its application in applied geotechnical engineering from A to Z and at the right depth for an undergraduate civil engineer, with sufficient extension material for supporting MSc level courses, and with practical examples and digital tools to make it a useful reference work for practising engineers.*' This textbook is explicitly composed of a 7-chapter part I 'Development of a mechanical model for soil' and a 6-chapter part II 'Applications in geotechnical engineering'. The book also features a companion website (https://routledgetextbooks.com/textbooks/9781138070066/), with additional teaching and learning resources, tailored to both students and educators. *Principles of geotechnical engineering* (10th ed., 2022) is marketed as an '*introduction to geotechnical engineering [..] ideal for the introductory course taken by most civil engineering students [..] [providing an] overview of soil properties and mechanics together with coverage of today's field practices and basic engineering procedures [..] [and] the background students need for advanced design-oriented courses as well as professional practice.*' The book comprises 19 chapters almost evenly balanced, in numerical terms, among introduction and basic characteristics of soils, fundamental soil mechanics topics, and geotechnical applications. Similarly to *KC2020*, also this textbook has online supplements. For students they are provided in a platform called WebAssign, in the form of questions, videos and tutorials, feedback on coursework and progress monitoring tools. For the instructors there is a Companion Site (https://companion-sites.cengage.com/) as well a learning platform called MindTap featuring dynamic applications and real-time course analytics.

3.4 Textbooks written in other languages

The non-English textbooks considered in this study are 18. They are written in 11 different languages (Table 2). Most of them had their last edition published less than 20 years ago (exceptions: *, CR-N1981, FR-S1997, TU-K1999, IT-C2004*), some of them are very recent (*CH-L2020, TU-U2020, IT-B2021, KO-L2021, CH-G2022, PO-M2024*), and in a couple of cases it was not possible to retrieve the date of publication (*AR-A2019, CH-S*). In terms of editions, the textbooks featuring more than three editions are in Chinese (*CH-L2020*), Italian (*IT-L2012, IT-B2021*), Portuguese (*PO-M2024*) and Turkish (*TU-U2020*).

No regional or national trends emerge from this sample of textbooks. However, a few comments on what is (or is not) addressed in these books can be made.

- The way books introduce the reader to the subject varies widely, both in terms of number of chapters devoted to this initial part and in how the initial description, characterization and classification of soils is presented (this is also true for textbooks written in English).
- Chapters specifically devoted to continuum mechanics concepts, as a way of introducing stresses and strains in soils, are present only in books written in a few languages: three books written in Italian (*IT-B2018, IT-C2004, IT-L2012*), the two French books (*FR-P2013, FR-S1997*), and the books written in Croatian (*CR-N1981*), Danish (*DA-O2012*) and Greek (*GR-K2016*).
- Books devoting one chapter specifically to soil water and to the concept of effective stress are a minority (*IT-B2021, IT-C2004, IT-L2012, KO-L2021, PO-D2006, TU-U2020*).
- All books devote at least one chapter to groundwater flow.
- All books devote at least one chapter to volumetric compressibility and/or consolidation.
- Almost all books devote one or more chapters to shear strength, with the notable exception of some French (*FR-P2013*) and Italian (*IT-B2018, IT-L2012*) textbooks, wherein this concept is addressed within wide-ranging chapters dealing with constitutive modelling.
- Chapters devoted to soil exploration or soil testing are present only in books written in a few languages: Italian (4 books), French (2 books), Greek, Croatian and Spanish (1 book each). Soil investigation is introduced in specific chapters in three books (*FR-P2013, IT-C2004, SP-M2007*), mechanical laboratory tests are addressed in 4 books (*GR-K2016, IT-B2018, IT-B2021*), and in-situ tests in 5 books (*CR-N1981, FR-S1997, IT-B2018, IT-C2004, IT-L2012*).

4 Topics addressed and sequence

4.1 Books' chapters and grouping of topics

To discuss the topics addressed in the analysed textbooks, it may be useful to group them in classes: i) introduction and basic characteristics of soils, ii) soil investigation and testing, iii) soil mechanics core concepts, iv) geotechnical applications. This grouping is evidently influenced by the many TOCs considered in this study but remains subjective. In fact, some books are explicitly structured in parts or sections that collect their chapters (e.g., *TPM1996* part A: Physical properties of soils, part B: Theoretical soil mechanics, part C: Problems of design and construction; *At2014*: Discovering the ground, Essential physics and mechanics, Soil mechanics, Geotechnical engineering; *KC2020* part I: Development of a mechanical model for soil, part II: Applications in geotechnical engineering), yet the majority of them only uses the chapters as the highest category of aggregation for the topics presented.

The number of chapters that may be associated with these four groups of topics varies greatly in the different textbooks. Also, the total number of chapters of each book is extremely variable, ranging from less than 10 to more than 20. The decision to use chapters for this study, rather than exploring TOCs at deeper levels, was based both on opportunity (e.g., time constraints, help with translations would have been needed for the books written in languages not spoken by the author) and methodological coherence. Sections and subsections may provide elements that are essential to properly understand the content of each chapter, particularly when few of them are employed. However, the choice to group topics within a single chapter, or the opposite one to use multiple chapters to deal with some topics, is an important decision authors of textbooks are asked to make when structuring a book and has therefore an inherent conceptual value. The comparison of the relative space the authors decided to devote to the four clusters of topics is conducted by attributing each chapter to one of the categories, counting them and then dividing, for each book, these numbers by the total number of chapters. Such a comparison (Figure 1) cannot capture the way topics are treated in the different books, nor the lengths of the different chapters, but graphically reporting this relative attribution allows identifying the books that most significantly differ from the others, for instance: three books written in English and many books written in other languages do not devote any chapter to soil investigation and testing; six books devote 50% or more of the chapters to geotechnical applications.

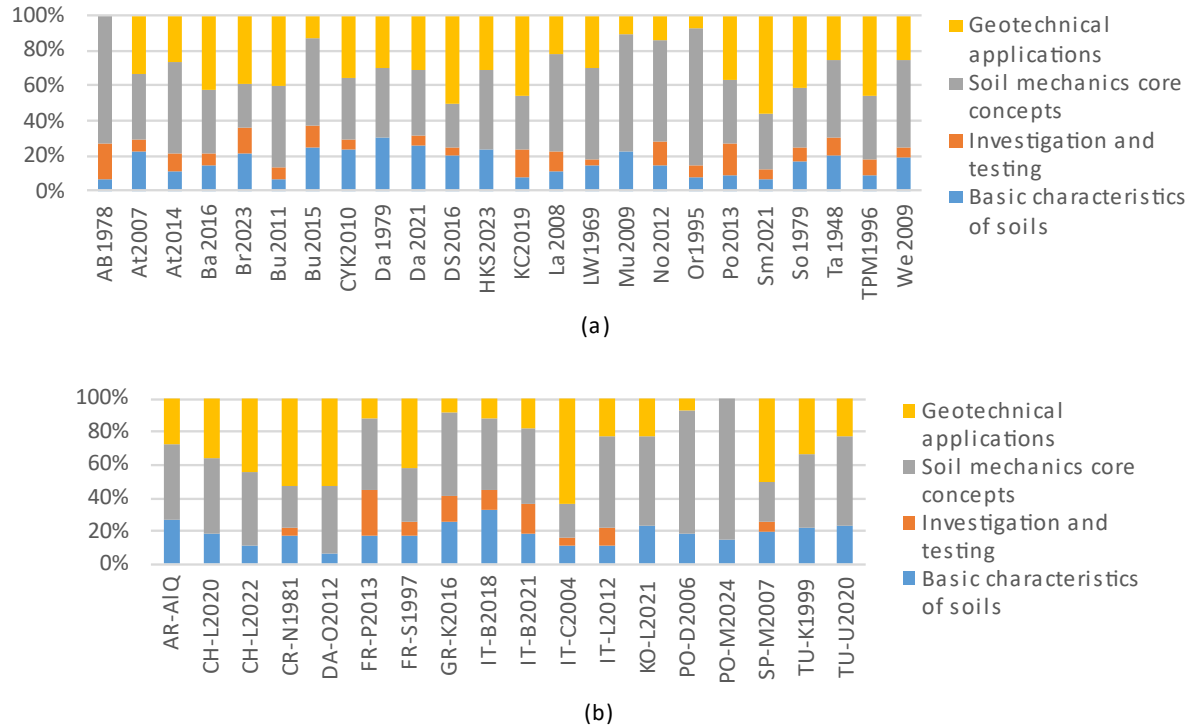

Figure 1. Relative space devoted to topics tied to basic characteristics of soils, investigation and testing, soil mechanics principles, geotechnical applications: a) books written in English and b) books written in languages other than English

4.2 Introduction and basic characteristics of soils

All books evidently start with introducing the subject of the textbook, and they continue by presenting the basic characteristics of the soils, essentially addressing soil physical properties and soil classification systems. Concerning the very first chapter(s), many books start by immediately dealing with classification or index properties (e.g., *Sm2021, TPM1996*), or with a short chapter simply called 'Introduction' (e.g., *IT-C20024, SP-M2007*), yet many others clearly highlight the "point of view" of the introduction in the title of their initial chapter (see Section 4.7 for examples). The most adopted choices are the following two:

i) introducing geotechnical engineering as a specialty branch of civil engineering (*At2007, CYK2010, HKS2023, LW1969, GR-K2016, IT-B2021*), in two cases including an historical narration (*Da2021, DS2016*);
ii) dealing with the origin and formation of soils and rocks (*At2014, Ba2016, Da1979, So1979, We2009, PO-D2006*), in a few cases specifically mentioning geology in the title of either the first (*FR-P2013*) or the second (*Bu2011, CYK2010, So1979*) chapter.

4.3 Soil investigation and testing

Soil investigation and testing is a topic that may be presented in different positions within the sequence of topics, depending on what exactly it refers to (i.e., soil exploration, laboratory testing, in-situ testing), as well as on the way it is addressed in relation to the core concepts of soil mechanics and on its use for addressing geotechnical problems.

Soil exploration, when treated, is mostly placed either after the chapters dealing with the basic characteristic of soils (*Bu2011, Bu2015, Ta1948, TPM1996*) or after the chapters dealing with soil mechanics core concepts (*DS2016, KC2019, Sm2021, So1979, We2009*). In two cases this subject is presented at the beginning of the book, before soil identification and classification (*CYK2010, FR-P2013*), and in another two cases at the very end of the book, after the geotechnical applications (*Da2021, Po2014*).

In-situ testing, when treated, is typically placed in the second part of the book, after the chapters dealing with soil mechanics (*At2007, KC2019, La2008, FR-P2013, GR-K2016, IT-B2021, IT-L2012, SP-M2007),* in the part devoted to geotechnical applications (*FR-S1997*) or after that, at the end of the book (*Ba2016, Po2014*). Exceptions include two books written in English (*At2014, Br2023*) and two books written in other languages (*CR-N1981, IT-C2004*), in which this topic immediately follows the introductory chapters.

Names used in the books written in English for chapters dealing with soil exploration and in-situ testing include soil (*Bu2011, Bu2015, Po2014, Sm2021, We2009),* ground (*At2014, KC2019*) and subsoil investigation *Da2021, DS2016, Ta1948*), soil and rock investigation (*So1979*), soil exploration (*TPM1996*), site investigation (*Ba2016, Br2023, KC2019, Po2014, We2009*) or exploration (*CYK2010*), in-situ testing or investigation (*Br2023, La2008, Po2014*), field testing (*We2009*).

Laboratory testing for characterizing the mechanical behaviour of soils is explicitly presented in stand-alone chapters in a minority of textbooks (9 written in English, 5 in other languages), mostly when theoretical soil mechanics concepts are addressed (*At2007, At2014, AB1978, Br2023, HKS2023, LW1969, No2013, Or1995, Po2014, IT-B2018*), in three cases at the very end of that part (*FR-P2013, GR-K2016, IT-B2021*).

4.4 Soil mechanics core concepts

The core of soil mechanics textbooks are soil mechanics concepts that characterize the discipline. Many of these core concepts are deeply interconnected and, in many cases, it is difficult to draw clear lines separating specific topics from each other, or to group these concepts coherently into broader themes, or even to agree on common names for soil mechanics topics, concepts and themes. For this very reason, I think it is relevant to try reporting and clustering these within a sort of map of soil mechanics core concepts treated in textbooks.

My efforts in this direction have led me to the definition of seven main soil mechanics themes, to which concepts and topics covered in textbooks can be associated. They are listed here below, together with the main concepts they include.

A. **Stresses and strains in soils** (including continuum mechanics basic concepts, stress paths, principle of effective stress, pore pressures, total stress, drained and undrained conditions)
B. **In-situ stresses** (including initial stresses and stress distribution below the ground surface, hydrostatic water pressures, stresses from surface loads, changes of stresses)
C. **Groundwater flow** (including flow in porous media, hydraulics of soils, stationary and transient conditions, one-dimensional and multi-dimensional flow)
D. **Stress-strain relationships** (including behaviour of material, elastic theory, constitutive models, deformation behaviour, soil behaviour in shear)
E. **Volumetric compression** (including volume change behaviour, compressibility, one-dimensional compression, soil settlements)
F. **Consolidation** (including pore pressures during undrained loading, one-dimensional consolidation, rate of consolidation, settlements of fine-grained soils)
G. **Shear strength** (including shear strength properties, critical state, peak states, drained and undrained shear strength)

This subdivision is surely arbitrary, as other educators may think that fewer or more themes, or a different type of grouping, can be used. In my proposed classification, continuum mechanics theory and stresses associated with the presence of water in the soil (theme A) and stress distributions in the ground (theme B) are two different themes because in the first case stresses (and strains) are discussed at the level of the representative elementary volume, while in the second case the space below the ground surface is explicitly considered. All the 42 analysed textbooks deal with these concepts, many textbooks (16 books) devote at least one chapter to both themes. The presence of water in the soil is key for many concepts associated with themes A and B, yet when the movement of the water in the soil pores is explicitly addressed, a different theme is considered (theme C). All 42 textbooks devote one or more chapters to groundwater flow. Stress-strain relationships could have been defined as a very wide theme associated with the presentation of elastic and elastic-plastic models, and such a theme could in principle include all types of soil deformations due to stress changes as well as failure (critical) states. However, differentiating between deformations induced by shear (deviatoric) stresses (theme D) and volumetric compression or swelling (theme E) allows to explicate the different stress-strain behaviour in the two cases. Consolidation (Theme F), despite being associated with volumetric compression, presents a clearly distinct soil feature associated with a foundational soil mechanical concept: time-dependent deformations due to the dissipation excess pore pressure. Finally, shear strength (theme G), another key concept for the mechanical characterization of soils, deserves to be mentioned separately and not only as a component of an elastic-plastic constitutive law. Slightly more than half of the books (24 books) include chapters that can be classified as dealing with stress-strain relationships. Almost all books (38 books) devote chapters to compression and consolidation; in some cases (10 books) these are presented within the same chapter. Almost all books (38 books) have chapters dealing with soil failure and shear strength.

Figure 2 shows a representation of the seven themes and of the soil mechanics concepts and topics they are mainly associated with, clustered around the theme. At times, some concepts are reported more than once, using slightly different terms, to explicitly consider wording used in the chapter titles of textbooks analysed herein. Adopting another type of representation, Figure 3 shows how these themes are addressed in each book. The capital letters associated with each theme (A to G) are listed in the order in which they appear in the TOC of each book, using different colours to enhance comprehension, as a sort of DNA sequence of the textbook in relation to the themes defined. These sequences portray how the book's authors decided to present to the readers the soil mechanics topics deemed most relevant.

The number of chapters used to address soil mechanics core concepts ranges from 4 to more than 10. At first sight, it may appear that each textbook has its own way of arranging these topics. However, some trends may be outlined. The first three themes (A to C) are typically preceding the other ones. When general concepts related to stresses and strains are present, they find a space in the first chapters of the sequence. However, a large number of books written in English start with a chapter presenting concepts related to groundwater flow (10 books). Concerning the first chapters of the books written in other languages, there is a wide distribution between all three themes: stresses and strains in soils (9 books), in-situ stresses (4 books), groundwater flow (5 books). Themes D to G are presented in a lot of different configurations. The only very common sequence that appears in many textbooks is volumetric compression and consolidation, either in the same chapter (7 books) or one after the other (4 books). Often, shear strength is concluding the sequence of these seven themes.

Figure 2. Proposed representation of the main soil mechanics themes (in bold) and of the associated concepts and topics addressed in the analysed textbooks

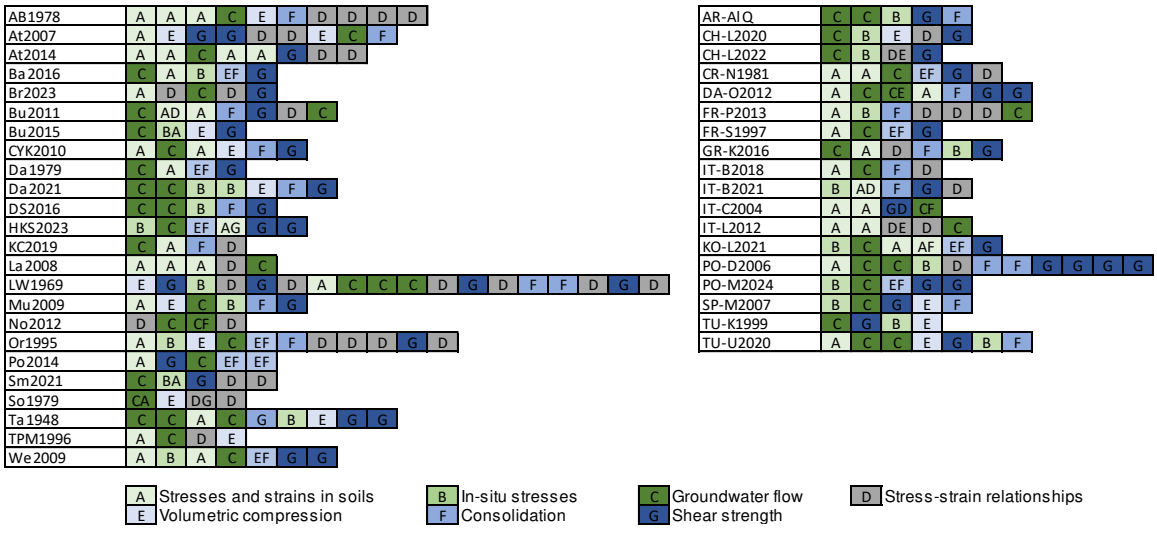

Figure 3. Proposed representation of the sequences of soil mechanics chapters in each textbook, classified according to the themes presented and ordered as they appear in the book

4.5 Geotechnical applications

Besides presenting fundamental soil mechanics, many of the textbooks listed herein also introduce the readers to basic concepts of geotechnical applications, by means of specific chapters devoted to them. As already mentioned, this is true also for many books titled 'Soil mechanics' or anyway lacking the words geotechnical or foundations in their title (*Ba2016, Da1979, KC2019, LW1969, Po2014, Sm2021, Ta1948, TPM1996, CH-G2022, CH-L2020, CH-S, FR-S1997, TU-K1999, TU-U2020*).

The main geotechnical applications addressed in textbooks are, as expected, the following three: i) foundations, ii) retaining structures, and iii) slope stability. In addition, some books also address other topics: earthworks (*Ba2026, KC2019, CR-N1981, IT-C2004*), soil improvement (*Br2023, DS2016, LW1969, IT-C2004*), geosynthetics (*Br2023, Da2021, IT-C2004*), earthquake engineering (*Br2023, CH-G2022, CH-L2020*), tunnelling (*At2007*), dams (*Ta1948, TPM1996*), geoenvironmental engineering (*Br2023*), erosion and scour (*Br2023*), road geotechnics (*FR-S1997*). Only few books written in English do not deal with geotechnical applications (*AB1978, Bu2015*) or present them very briefly in a final chapter as an introduction to more specialised textbooks (*Mu2009, No2013, Or1995*). Slightly more are these purely soil mechanics books written in other languages (*AR-A2019, FR-P2013, GR-K2016, IT-B2018, IT-B2021, IT-N2002, KO-L2021, PO-D2006, PO-M2024*).

4.6 Trends over time

Books with multiple editions published over time, with enough time difference among them, can be analysed to understand the decisions made by the authors in updating the content. An interesting case study is the book *An introduction to geotechnical engineering* (*HKC2023*), whose first edition was published in 1981 by Holtz and Kovacs. The first edition of the book was: *'intended for use in the first of a two-course sequence in geotechnical engineering usually taught to third- and fourth-year undergraduate civil engineering students. We assume the students have a working knowledge of undergraduate mechanics [..] knowledge of basic geology, although helpful, is not essential. We introduce the "language" of geotechnical engineering in the first course*'. The most significant change that occurred in these 40 years (in fact between the 2nd edition published in 2011 and the last one) is the addition of three chapters devoted to shallow foundations, lateral earth pressures and earth retaining structures, and deep foundations. The presentation of the last edition reads as follows: '*To place theory into context, the engineering significance of the property being discussed is presented, along with why the property is needed, how it is determined or measured, and how it is used in specific design situations.*' Other (less significant but nevertheless important) changes also have occurred. In the initial part, the first two editions had a chapter on clay minerals of soil structures, not present in the last edition; starting from the second edition a new chapter on geology, landforms and the origin and evolution of geomaterials was added. Some changes in names and some grouping occurred in the central chapters devoted to the soil mechanics core concepts yet keeping the same sequence of topics: water in soils, compressibility and consolidation, failure. Finally, from the 2nd edition, in addition to the two chapters already dealing with failure theories and shear strength, a final chapter is present on Advanced topics in shear strengths of soils and rocks.

Another case study is *Craig's soil mechanics* (*KC2020*), whose first and last editions were published in 1974 and 2020, respectively. Besides the significantly increased space devoted to geotechnical applications, the most significant changes in the structure of the first part of the textbook, i.e., the part addressing soil mechanics concepts, occurred between the 7th ed. (2004) and the 8th ed. (2012), which is the first edition co-authored by J. Knappett, who writes: '*I felt that the time was right for a major update [..] though I have tried to maintain the clarity and depth of explanation which has been a core feature of previous editions. [..] It is still intended primarily to serve the needs of the undergraduate civil engineering student and act as a useful reference through the transition into engineering practice. However, inclusion of some more advanced topics extends the scope of the book, making it suitable to also accompany many post-graduate level courses.*' In terms of structure and focus of part I, for the first time called 'development of a mechanical model for soil', the changes were significant. Only the first three chapters retained titles and position: basic characteristics of soils, seepage, effective stress. Shear strength and stresses and displacements, are preceded by a chapter on consolidation, previously addressed in the last chapter of this theoretical part, and these concepts are presented in one chapter titled: soil behavior in shear. Part I of the book ends with two chapters devoted to ground investigation (previously placed after foundations and slope stability) and in-situ testing. Lateral earth pressures, previously presented as an autonomous chapter in the first part, are inside the chapter in part II devoted to retaining structures.

4.7 Specific points of view

A few textbooks may be considered unusual as they intentionally approach the introduction to soil mechanics from a specific point of view, and this intention is often stated in the title of the book.

- *The mechanics of soils: an introduction to critical state soil mechanics* (*AB1978*), and *Soil mechanics in the light of critical state theories* (*Or1995*), address soil mechanics mainly considering the framework of critical state theory. It must be noted that these are not the only books treating critical state soil mechanics, which is indeed specifically mentioned in the name of a chapter in other four books (*At2007, At2014, Bu2011, Sm2021*) but is also treated in many other textbooks when soil constitutive modelling or shear strength concepts are presented.
- *Fundamentals of soil mechanics for sedimentary and residual soils* (*We2009*). The need for such a book lies in the fact that '*despite its prevalence in under-developed parts of the United States and most tropical and sub-tropical countries, residual soil is often characterized as a mere extension of conventional soil mechanics in many textbooks. [..], with the rapid growth of construction in these regions, it is essential to gain a fuller understanding of residual soils [..] based on an integrated approach to the study of residual and sedimentary soils*.'
- *Geotechnical engineering: unsaturated and saturated soils* (*Br2023*). 'Why this book?' is the title of the first section of the first chapter of the book, wherein the author reports a quote by Albert Einstein '*Things should be made as simple as possible but not a bit simpler than that*' and states '*The first driving force for writing it was the coming of age of unsaturated soil mechanics: [..] to introduce geotechnical engineering as dealing with true three-phase soils while treating saturated soil as a special case, rather than the other way around. The second driving force was to cover as many geotechnical engineering topics as reasonably possible in an introductory book, to show the vast domain covered by geotechnical engineering*.'
- *Soil mechanics: a one-dimensional introduction* (*Mu2009*). The author states: '*in the context of teaching principles of soil mechanics to undergraduates in the early years of their civil engineering degree programmes, I believe that there is advantage to be gained in trying to integrate [..] teaching of properties of engineering materials to which the students are being exposed at the same time. [..] [which] prompted me to explore a [..] one-dimensional theme for the presentation of many of the key concepts of soil mechanics: density, stress, stiffness, strength and fluid flow. This one-dimensional approach to soil mechanics has formed the basis for an introductory course of ten one-hour lectures with ten one-hour problem classes and one three-hour laboratory afternoon for first-year civil engineering undergraduates.*'

4.8 Other comments

The topic of compaction appears in many soil mechanics textbooks, albeit not in most of them. When it is addressed, its relative position varies significantly. Indeed, this topic is at times discussed after presenting the basic characteristics of soils (*DS2016, HKS2023, CYK2010, Bu2011, Da2021, PO-D2006, KO-L2021*), at times when discussing soil mechanics concepts (*Bu2015, AR-A2019, TU-U2020, IT-C2004*), and at other times when the geotechnical applications are presented (*Br2023*), mostly at the very end of the book (*Sm2021, We2009*). To explain this finding, one may consider that this topic relates to the realization of geotechnical works with a long empirical tradition for situations where the soil is used a construction material in earth fills or embankments, yet the behaviour of soils undergoing compaction can be explained theoretically only by considering the mechanics of soils in partially saturated conditions. Only a minority of textbooks devote at least one full chapter to unsaturated soil mechanics (*At2007, At2017, Br2023, FR-P2013, PO-M2024*). Therefore, it should not come as a surprise if many authors decide not to treat soil compaction in textbooks that introduce students to the main concepts of soil mechanics without considering unsaturated conditions such as, among others: the oldest textbooks written in English (*Ta1948, LW1969, So1979, TPM1996*), with the notable exception of the textbook written by Holtz et al. (*HKS2023*) since its first edition in 1981. The titles of these chapters may also be indicative of how this subject is treated. In the four books where this chapter is not simply called 'Compaction' or 'Soil compaction' the following titles are used: 'Compaction and stabilization of soils' (*HKS2023*); 'Excavation, grading, and compacted fill' (*CYK2010*); 'Soil compaction, highway foundation design and ground improvement' (*Sm2021*).

Almost all books introduce the theoretical concepts for soils in general, rather than devoting entire chapters at discussing aspects of the mechanical behaviour of only sands or clays. Exceptions to this rule are the following: all the three textbooks written by Portuguese or Brazilian authors (*PO-D2006,*

PO-M2024, Or1995) and the old textbook by Taylor (*Ta1948*), which present the concept of soil strength separately for sands and clays, with *PO-M2024* also calling one chapter “Compressibility and consolidation of clay layers” and *PO-D2006* devoting the final chapter of the book to the “Behaviour of some typical soils”.

5 Concluding remarks

The research conducted herein had the aim to identify commonalities and divergences in topic coverage and topic sequence in introductory soil mechanics and geotechnical engineering textbooks written in different times and different languages. The insights gained from this comparative analysis could serve as a valuable resource for educators seeking to refine their course content and could also potentially inform future textbook editions. Different geotechnical educators, reading in this article, will probably focus their attention to different findings, e.g., landmark books, intriguing sequences of topics, specific names used to address concepts, new references to explore. All of them will hopefully find some good “food for thought” for their educational activity.

As a byproduct of this study, a relatively long list of textbooks, written in English and in other languages, was compiled and discussed. Even if the search that led to this list cannot be considered comprehensive or systematic, it is the opinion of the author that most of the relevant books, especially the ones written in English, have been considered herein. This list may prove useful to many, as a source of information on textbooks currently available. For instance, books previously unknown to some educators may be discovered as resources of educational material suiting their own style of teaching. Possibly, this list can also be used as a sort of reading list for geotechnical engineering teachers wanting to deepen their knowledge on specific aspects of the discipline or to delve deeper into the historical writings of educators from the past. It would not be surprising if some of the readers may find this list, as such, the most important product of this article.

Acknowledgements

Thanks to all the members of the ISSMGE Technical Committee 306 “Geo-engineering education” who have helped me in gathering the materials used in this article, and special thanks to the Chair of TC306, Marina Pantazidou, for her motivation to address this topic, for many inspirational conversations, and for personal notes passed to me specifically for this study.

References

Al-Qasabi, S.A.F. (2019). ميكانيكا التربة., Egypt.

Atkinson, J.H. (2007). The Mechanics of Soils and Foundations, 2nd ed. Taylor & Francis, Oxon, UK.

Atkinson, J.H. (2014). Fundamentals of Ground Engineering. CRC Press, Boca Raton, USA.

Atkinson, J.H., Bransby, P.L. (1978). The Mechanics of Soils: An Introduction to Critical State Soil Mechanics. McGraw-Hill, New York, USA.

Barnes, G. (2016). Soil Mechanics: principles and practice, 4th ed. Bloomsbury Publishing, London, UK.

Berardi, R. (2021). Fondamenti di geotecnica, 4th ed. CittàStudiEdizioni, Tonino, Italy.

Briaud, J.L. (2023). Geotechnical Engineering: Unsaturated and Saturated Soils, 2nd ed. Wiley, Hoboken, USA.

Budhu, M. (2011). Soil mechanics and foundations, 3rd ed. Wiley, Hoboken, USA.

Budhu, M. (2015). Soil Mechanics Fundamentals, metric version. Wiley, Hoboken, USA.

Burghignoli, A. (2018). Meccanica delle terre. Hevelius edizioni, Benevento, Italy.

Coduto, D.P., Yeung, M.R., Kitch, W.A. (2010). Geotechnical Engineering: Principles & Practices, 2nd ed. Pearson, London, UK.

Colombo, P., Colleselli, F. (2004). Elementi di geotecnica, 3rd ed. Zanichelli, Bologna, Italy.

Das, B.M. (1979). Introduction to soil mechanics. Ames: Iowa State University Press, Ames, USA.

Das, B.M. (2021). Principles of Geotechnical Engineering, SI edition, 10th ed. Cengage, Boston, USA.

Das, B.M., Sivakugan, N. (2016). Fundamentals of Geotechnical Engineering, 5th ed. Cengage, Boston, USA.

De Sousa Pinto, C. (2006). Curso básico de mecânica dos solos, 3rd ed. Oficina De Textos, Sao Paulo, Brazil.

Holtz, R.D., Kovacs, W.D., Sheahan, T.C. (2023). An introduction to geotechnical engineering, 3rd ed. Pearson, London, UK.

Kavvadas, I.M. (2016). Στοιχεια εδαφομηχανικησ, 2nd ed. Συμεων εκδοσεισ, Athens, Greece.

Knappet, J.K., Craig, R.F. (2019). Craig's Soil Mechanics, 9th ed. Routledge, Milton, UK.

Kumbasar, V., Kip, F. (1999). Zemin Mekaniği Problemleri. Çağlayan Kitabevi, Istanbul, Turkey.

Lambe, T.W., Withman, R.V. (1969). Soil Mechanics. John Wiley & Sons, Hoboken, USA.

Lancellotta, R. (2008). Geotechnical Engineering, 2nd ed. CRC Press, Boca Raton, USA.

Lancellotta, R. (2012). Geotecnica, 4th ed. Zanichelli, Bologna, Italy.

Lee, I.M. (2021). 토질역학의 원리, 3rd ed., Korea.

Li, G., Zhang, B., Yu, Y. (2022). 土力学, 3rd ed. Tsinghua University Press, Beijing, China.

Liu, S. (2020). 土力学, 5th ed. China Architecture & Building Press, Beijing, China.

Matos Fernandes, M. (2024). Mecânica dos Solos. Conceitos e Princípios Fundamentais, 6th ed. U.Porto Press, Porto, Portugal.

Mitchell, J.K., Soga, K. (2005). Fundamentals of Soil Behavior, 3rd ed. Wiley.

Muir Wood, D. (2009). Soil mechanics: A one-dimensional introduction. Cambridge University Press.

Muzas Labad, F. (2007). Mecánica del suelo y cimentaciones. Fundación Escuela de la Edificación.

Nonveiller, E. (1981). Mehanika tla i temeljenje građevina. Školska knjiga, Zagreb.

Nova, R. (2013). Soil Mechanics. Wiley, Hoboken, USA.

Ortigao, J.A.R. (1995). Soil Mechanics in the Light of Critical State Theories. Routledge, Milton, UK.

Ovesen, N.K. (2012). Lærebog i Geoteknik, 2nd ed. Polyteknisk Forlag, Lyngby, Denmark.

Plumelle, C. et al. (2013). Théorie et pratique de la géotechnique. Le Moniteur Editions, Gentilly, France.

Powrie, W. (2013). Soil Mechanics: concepts and applications, 3rd ed. CRC Press, Boca Raton, USA.

Schlosser, F. (1997). Eléments de mécanique des sols, 2nd ed. Presses de l'école nationale des Ponts et Chaussées, Paris, France.

Smith, I. (2021). Smith's Elements of Soil Mechanics, 10th ed. Wiley-Blackwell, Hoboken, USA.

Sowers, G.F. (1979). Introductory soil mechanics and foundations, 4th ed. Macmillan, New York, USA.

Taylor, D.W. (1948). Fundamentals of soil mechanics. Asia Publishing House, Bombay, India.

Terzaghi, K., Peck, R.B. (1948). Soil Mechanics in Engineering Practice. John Wiley, Hoboken, USA.

Terzaghi, K., Peck, R.B., Mesri, G. (1996). Soil Mechanics in Engineering Practice, 3rd ed. Wiley, Hoboken, USA.

Uzuner, B.A. (2020). Temel Zemin Mekaniği: Çözümlü Problemlerle. Derya Kitabevi, Gölcük, Turkey.

Wesley, L.D. (2009). Fundamentals of soil mechanics for sedimentary and residual soils. Wiley, Hoboken, USA.

Author's bio

Michele Calvello, University of Salerno, Italy

Michele Calvello is full professor in geotechnical engineering at the University of Salerno (Italy), where he currently teaches "soil mechanics" and "landslide risk". He graduated with honours in civil engineering from Università della Basilicata (Italy) in 1997, and he earned a PhD degree from Northwestern University (USA) in 2002. His main research interests are focused on the engineering analysis of geotechnical boundary value problems and on the analysis and management of landslide risk, with special attention devoted to the following inter-disciplinary topics: early warning systems, landslide zoning, risk perception, risk education and community resilience. Currently he is the president of "LandAware – the international network on landslide early warning systems", the Principal Investigator of the Horizon Europe project "The HuT. The Human-Tech Nexus – Building a Safe Haven to cope with Climate Extremes", and the co-Coordinator of the LARAM School, an International School for PhD students on "LAndslide Risk Assessment and Mitigation". He is a member of the Editorial Board of the journals Georisk, Geoenvironmental Disasters, Landslides and Rivista Italiana di Geotecnica. He is Secretary of the ISSMGE Technical Committee TC-306 "Geo-Engineering Education".