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Discussion of "Teaching Modern Soil Mechanics"*

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Discussion

1. Introduction

The paper deals with the incorporation of Critical State Soil Mechanics (CSSM) in the syllabus of undergraduate courses and the difficulties arising when Classical Soil Mechanics (CSM) content is included as well. Although the title seems to refer to pedagogical aspects, the objective is to point out how difficult is to combine both theories.

I am particularly grateful to the author for presenting this topic in an issue about Geo-Education and I fully agree with the idea that basic CSSM concepts should be introduced at undergraduate level. This type of papers represents an opportunity to highlight the importance of a discussion that seems to be a "never-end story" in the last decades. Some previous examples on this discussion are the paper by Airey & Miao (2016) supporting teaching CSSM concepts, and the paper by Wesley (2015) defending the opposite.

Despite what is suggested in the paper, my feeling is that the number of undergraduate Soil Mechanics courses not including Critical State concepts is still important, if not increasing. This is consequence of the approach to Geotechnical Engineering that may focus on practical applications using CSM, rather than on fundamental modern concepts behind CSSM. That may be due to external constraints as well. In this discussion I try to present some ideas about this conflict between theories and how they can be implemented in the syllabus at undergraduate level.

2. External constraints

When defining a syllabus of a Civil Engineering undergraduate degree, there are many conditions that have influence on the topics covered. The obvious one is the number of courses dealing with Geomaterials, i.e. Geology (a subject usually not well covered in Secondary Education), Soil Mechanics (basic concepts) and Geotechnical Engineering (design of foundations, walls, etc.). The number of courses on Mechanics, including Elasticity and Plasticity, included in the syllabus, can constitute a constraint as well. Thus, the contents of a Soil Mechanics course depend on what are the other related courses in the Degree.

In addition to that, Civil Engineering degrees have a long tradition of including a lot of Structural and Construction topics in the syllabus. Tradition is difficult to modify in this case, as construction industry still employs many Civil Engineers around the world. However, this is probably changing in the profession, incorporating new topics which are particularly important in our Geo-engineering field, as Geo-Environment, Geo-Energy, Geo-planning, etc. Including those topics in the syllabus is difficult as time is limited and classical topics as "Foundations" and "Walls" seem to have priority.

Having these constraints in mind, I think the courses should focus on the fundamental scientific contents that are not conjunctural, as supported by Santamarina (2015). To this respect, CSSM is a fundamental framework that helps to mentally organize ideas about soil behaviour.

3. Reasons supporting teaching CSSM

There are many reasons to teach basic concepts of CSSM at undergraduate level. The paper by Prof. Maranha das Neves indicates some of the advantages of the theory with respect CSM, but I think it would be useful to present some general reasons rather than academic improvements of the new theory, in order to contribute to the debate. I would like to add some general reasons:

a) As indicated by the author, Plasticity is a fundamental mechanical concept for Civil Engineers. Usually it is introduced in Structural Engineering subjects, defined in 1D conditions and considering perfect plasticity, because this may be sufficient in the context of steel and concrete structures. However, when working with soils, the concept of work-hardening (and softening) becomes fundamental. A 2D yield surface is the natural extension of the 1D representation, highlighting the fact that the elastic limit is not constant and the yield surface can expand or contract. Some of the concepts of the Cam-clay model may be taught as well, even at undergraduate level. Generally, for clayey normally consolidated soils, the elastic region is small and increases when reducing void ratio (strain hardening model). Therefore understanding plasticity is a key aspect of soil behaviour, not only

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the concept of Critical State, but also some of the ideas behind the Cam-clay model;

b) Understanding the effect of loading and unloading processes is very important as well. Natural or artificial processes may change the effective stress and apply a loading/unloading stress history to the soil. In addition to that, the simple fact of taking out a sample of a fine soil from the field and bringing the sample to the laboratory is an unloading process in terms of total stresses. The sample in the laboratory is then reloaded (i.e. in a triaxial device). If the confinement in the laboratory is less than the "in situ" confinement, the sample may behave as over-consolidated, even if it is normally consolidated in the field. Understanding the role of the loading and unloading processes and the stiffness associated to each path is necessary to understand soil behaviour, and that is easier when using the framework provided by CSSM;

c) In the CSM books, Normally-consolidated and Over-consolidated clayey soils were "different" materials. Each material had a different chapter or section describing its mechanical behaviour. However, it is absurd that the same clayey soil could have different parameters depending on the loading-unloading history. CSSM provides a single set of parameters for the soil, and loading history is just that. That is, CSSM presents a "reference" and "unified" model for clayey soils, irrespective of the loading history. Obviously, many soils depart from the reference conditions, but this is part of the business when dealing with a natural material.

4. A proposal to combine CSM and CSSM

Outside University, practitioners use mostly CSM, although an important group of engineers are familiar with CSSM concepts already. In fact, using numerical methods in complex projects requires to know CSSM concepts. When teaching Soil Mechanics, therefore, it is important to devote some time to both theories despite their contradictions.

A possibility is to teach first the Soil Mechanics concepts developed up to, say, 1960's and after that show the later findings, including CSSM. The students should identify each concept associated to a historical period.

The second possibility is to present first CSSM concepts in the syllabus, and to introduce CSM later as a simplification or as an old approach to the problem. For instance, Mohr-Coulomb strength criterion is compared with the Critical State Line, and the "cohesion" and "friction angle" for peak conditions and for constant volume conditions in the Mohr-Coulomb envelope can be understood if the CSSM concepts have been presented previously. A historical perspective should be indicated to the students so they can recognize the evolution of the approaches along Soil Mechanics History.

Actually, this last possibility is the one I prefer. Combining CSM and CSSM requires an important effort and time for instructors and students, starting with the difficulties related to the use of different variables to work in each theory (Lambe or Cambridge mean effective stress and deviatoric stress). This is similar to showing young students Physics International Units and other Units (Imperial, etc.). Both should be taught for the moment if both are used in practice.

5. Conclusion

To summarize, I would like to point out the importance of including CSSM concepts at undergraduate level. This agrees to what Professor Maranha das Neves indicates in his paper. However, I want to stress that still many instructors consider that theory useless at undergraduate level, and therefore, it is important to convince about its advantages with respect CSM. I have included some general reasons for claiming that, rather than specific reasons.

The difficulties and contradictions between CSM and CSSM presented in the paper by Prof. Maranha das Neves can be overcome when teaching Soil Mechanics if CSSM is taught first and CSM later, adding always a historical perspective to the topics.

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