Università degli Studi della Campania *Luigi Vanvitelli*

Dipartimento di Ingegneria

External reviewer's report for:

"*Experimental approaches to evaluate temperature and time-dependent effects in sheared soil"*

A thesis submitted by Mr. Tomáš Mladý in partial fulfilment of the requirements for the Master's degree in Engineering Geology at Charles University, Faculty of Science, Prague, Czech Republic.

Brief description of the work

The objective of Mr. Mladý's thesis was to design a direct shear apparatus to investigate the role of temperature on time-dependent effects, so as to understand the onset and evolution of shear creep in soil subjected to variations in temperature.

The candidate used an old commercial shear box device with a faulty motor. The motor was removed, and the device was adapted by the candidate to apply a constant shear load to the soil sample contained in a conventional shear box. Application of a constant shear load was ensured by a system consisting of a wire, a pulley, and a frame on which dead loads were applied. Other modifications were made to ensure the machine's operations, which also entailed 3D-printing and writing original pieces of software. The control over the soil temperature was achieved by connecting the device to a thermostatic bath by means of a closed circuit in which water flow was enabled by a pump. This way, by regulating the temperature of the thermostatic bath, the bath in the shear box also could be heated, and heat could be transferred to the sheared soil. Temperature sensors were added to the device to monitor the process.

After a thorough description of the modifications and the related challenges, the candidate demonstrated through some preliminary experiments that the modified device was indeed capable of enabling the observation of shear creep, both via mechanical loading at room temperature and by heating. The study was introduced by an extensive literature review that the candidate conducted to comprehend the creep phenomenon and the relevance of thermal effects in landslides, and to compare and identify strengths and weaknesses of various experimental devices.

Detailed description, originality and quality of the work

The work begins with an introduction in which the candidate builds a case for the study of thermal effects. Landslide processes are introduced and defined, and their impact is pointed out. The candidate makes a link between climate change and landslides, highlighting sensitivity for their socio-economic consequences. Of course, these considerations could be broadened to other natural hazards. The candidate is aware of the major role of precipitation in triggering landslides and presents different examples, mentioning the underlying mechanisms. He then proceeds with noting that the literature does not offer sufficient insight into the role of temperature as a factor directly affecting slope stability (whereas effects of rapid warming on snow melting or thawing are known). Key motivation for his thesis thus comes from recently published works (Garcia, Loche, Shibasaki) that suggest a direct relationship between temperature and the residual shear strength. This can obviously be relevant in landslide studies when existing clay shear zones are considered.

On a more practical level, the study is motivated by the need to more closely reproducing the mechanical condition of sheared soil and obtain data that could be used for calibration of constitutive models. It is thus considered that, being gravity the "motor" of landslides, shear creep experiments (force-controlled) should be more appropriate compared to conventional direct shear experiments (displacement-controlled) for the study of landslide shear zones. I agree with this view when it comes to evaluate the sensitivity of the residual shear strength to various external conditions. I also agree that commercial devices are not ideal for creep tests if they are realised with a servo-motor system (that is, when the shear velocity is adjusted according to the measured shear resistance in a feedback loop). Such a system does not in fact guarantee constant force conditions. The issue is similar to that occurring in swelling pressure tests performed in traditional oedometers, where a feedback system can increase the normal load to prevent swelling, but in order for the system to be triggered, some small swelling has to occur, which makes the experiment imperfect (not really a constant-volume experiment).

Chapter 2 of the thesis reviews classic knowledge on the behaviour of sheared soil, especially referring to the works of Skempton and Atkinson. The candidate defines and explains the relevance of the peak, critical and residual shear strengths, also pointing out the role of the stress history in (not) controlling these parameters. The candidate demonstrates good familiarity with these concepts. I especially appreciated the explicit mention of anisotropy and heterogeneities caused by shearing (obliteration of stress history effects, strain localization, particle migration or crushing, formation of slickensides).

The candidate shows awareness of the dependence of the residual shear strength on the rate of shearing (section 2.2), then proceeds to presenting general knowledge of soil creep (section 2.3), mainly based on the work of Augustesen et al., case studies (section 2.4), and a micro-mechanical understanding of creep (section 2.5). The latter section is particularly detailed, and the candidate proposes, quoting recent work by Yuan et al., that creep strains could be explained in clays by alterations in the diffuse double layer and that clays exhibit enhanced creep phenomena owing to the prevalent double layer interactions as opposed to direct particle-particle contacts. Indeed, this would suggest that the residual state in clays is the most conducive to creep (and rate-effect) phenomena. I find the considerations presented in this section rather promising and worthy of being developed further via future experimental work of the candidate.

Chapter 3 provides an overview of experimental devices capable of evaluating creep, rate effects, and temperature effects. Considering the candidate's focus on the residual condition, oedometer and triaxial machines are excluded from the review. The chapter begins with a description (section 3.1) of the direct shear box and its use for the evaluation of creep, with several examples of modified devices found in the literature. The descriptions are detailed and exhaustive, although some figures or schematics of the devices would have facilitated the reading. Similarly, a table comparing the various technical solutions could have been helpful. I found the description of an in-situ creep test (section 3.1.1) taken from Wang et al. quite valuable because such experiments are challenging and rare in the field. Nevertheless, the use of a feedback loop is a recognised limitation that also occurs in laboratory designs. Further on, a similar review is provided for ring-shear devices (section 3.2) and cases from the literature are reported. Finally, in sections 3.2.1 and 3.3, the impact of temperature is reviewed, with a focus on the residual shear strength and shear creep, and on the strategy to evaluate this impact via laboratory experiments. In section 3.2.1, in particular, the candidate points out limitations of the current set up implemented in his local laboratory, which could be overcome during the candidate's future work.

Detailed descriptions of the experimental device and its modifications are provided in Chapter 4 and Chapter 5 of the thesis, respectively. The candidate used a conventional direct shear box accommodating a cylindrical sample (6 cm diameter, 4 cm height). There is nothing peculiar regarding the apparatus (a commercial apparatus) but there are well known limitations correctly highlighted by the candidate. One of the issues with the machine's design is the single-point application of the normal load on the top cap: if the sample is not perfectly homogeneous and the assembly is not perfectly symmetrical, a small load imbalance can cause the cap to tilt and this tilt will only increase during the test, potentially causing issues with the distribution of the load. Combining this with the use of a load multiplier, the issue of tilting can become even more severe in the shearing/creep phase.

In Chapter 5, the candidate shows a good command of the functioning of the experimental devices and discusses in detail while the use of a motor with a feedback look is not advisable. Again, I agree with the candidate's view. The alternative (chosen) solution is to apply a dead load by means of a wire and a pulley to convert the vertical load into a horizontal pull. This solution is technically simple but not exempt from issues, and the candidate is well aware of these (section 5.1). Further, section 5.2 contains an interesting comparison of measurements with a laser and with a more conventional indicator. The lower accuracy of the laser is quite surprising.

Chapter 6 is dedicated to the introduction of temperature control capabilities. The candidate demonstrates to have thought about many details and things that could go wrong in this implementation and in carrying out temperature-controlled experiments. There is certainly originality in this part of the work. I mostly appreciated the discussion on the measurement system and the subsequent original design of an acquisition system (Chapter 7).

Chapter 8 describes the first tests in the modified apparatus, and a first preliminary evidence of shear creep activated by an increase in temperature and resulting in a permanent displacement is shown. On the other hand, heating-induced acceleration to failure or enhanced secondary creep were not captured. However, the device was shown to be capable of sustaining a full experiment at room temperature (see Fig. 10). This device testing phase should be obviously extended further to understand and address existing limitations and develop a solid testing protocol. Nevertheless, the first results are encouraging, and the scope of the thesis can be considered fulfilled, as long as this work will go on further in the coming months within the candidate's doctoral research.

Chapter 9 and chapter 10 present a discussion of the preliminary results and plans for future research work. It seems to me that the candidate is well aware of the issues related to his implementation and has a clear understanding of the tasks ahead. I feel the candidate is confident and will be able to manage the upcoming work successfully. I am looking forward to read about the future use of the apparatus and the implications of the findings for the understanding and modelling of landslides.

Finally, I appreciated that the thesis was written in a very clear language and was pleasant to read.

Remarks and questions

1) The reviewer appreciates the motivation behind the work done by the candidate, that is the possibility that changes in ground temperature affect the stability of slopes by altering their shear strength. This argument finds support in the recent literature but relationships between temperature and various geotechnical parameters have been known for a long time. It is conceded that these relationships do not typically find applications in general geotechnical designs but are reserved to specific subfields. Nevertheless, I solicit the candidate to provide his opinion on the actual novelty contained in the recent literature. The candidate should consider the work of Prof. Mitchell, who was already quantifying the effects of temperature on peak strength, compressibility, and more, as the candidate rightfully acknowledged later in the third chapter.

2) In Chapter 2, the candidate discussed various contributions from the literature concerning creep phenomena in soils. He also dedicated one section to the effect of the rate of shearing on the measured shear strength but did not make strong connections with the other sections of the chapter. Time-dependent displacements under a constant shear load and rate effects evaluated in rate-controlled experiments are two phenomena that can be considered two aspects of the same process (soil shearing) and derive from the different boundary constraints. As a matter of fact, this was pointed out by Czech scientist J. Feda in the 1980's. I thus invite the candidate to discuss the duality between rate effects and creep and the modelling framework that was proposed to jointly interpret them.

3) In section 2.4, the candidate provided examples of creep in landslides and mentioned the case of the "Costa della Gaveta" earthflow in Italy, which has been studied in detail by the research group led by C. Di Maio. An interesting observation was made regarding seasonal accelerations and decelerations of the landslides, associated with changes in pore water pressures. The candidate argued that a mechanism of shear-rate strengthening could explain the observed behaviour of the landslide. Then, for another case study (Vajont landslide) a mechanism of weakening was introduced to explain the catastrophic event. Can the candidate elaborate on the way strengthening and weakening mechanisms can prevent or induce fast landslides? Do these have anything to do with non-Newtonian behaviours of

soils? How do they depend on particle-level interactions (such as diffuse double layer interactions)?

4) Reading the various technical solutions for the evaluation of shear creep in the residual condition (Chapter 3) and the solution developed by the candidate, I find the use of a multiplier for the normal load to be a limitation of the adopted design because it introduces a physical constraint (the pivot of the lever) that may limit the horizontal displacement of the sample. Could the candidate discuss this limitation and whether a solution without the multiplier has been or will be considered? Further to this, what other technical improvements could be included in the candidate's design, according to his literature review?

5) In section 3.1.1, the candidate mentioned possible scale effects that may cause laboratory results (obtained with samples of various size) and field results or evidence not obviously relatable. Scale effects are indeed a recurring issue in the study of landslides by means of laboratory investigations and modelling. The candidate is invited to comment on the importance of these scale effects in the determination and use of various geotechnical parameters relevant to landslides.

6) In section 3.3, the candidate reported on ring-shear experiments, some of which were performed by Loche and Scaringi on bentonite and kaolin. Very recently, a preprint was published (Dhakal et al., https://doi.org/10.31223/X5HH6H), where similar experiments were conducted on natural landslide soils. I believe this study was not discussed in the thesis because at the time of submission it was not yet published. I believe, however, that the candidate is aware of this study and could comment on key differences between the thermal sensitivity of pure clays and that of natural soils. How does the abundance of clay mineral affect the temperature- and rate-dependent behaviours?

7) With respect to the design presented in Chapter 4 and also in relation to my question n. 4, I would appreciate it if the candidate discussed the issue of the tilting of the top loading cap, whether this is a common issue in direct and ring shear devices or if some devices can overcome this issue, and what does this issue imply in terms of quality/reliability of the experimental result (e.g., in terms of transmission of the load, lateral friction). Has the candidate thought about possible solutions to prevent tilting in his experimental design?

8) I agree with the candidate that the use of a dead load should be preferrable compared to the use of a motor with a feedback loop for the evaluation of shear creep. This simple design has nevertheless limitations, some of which have been discussed in section 5.1. The candidate could explain these issues to the commission. In particular, how did the candidate evaluate the loss of load caused by the friction of the wire with the pulley? How was the horizontality of the wire ensured through the tests, while the shear box was advancing and perhaps tilting? How was the displacement limited to a maximum value to prevent the box from hitting other parts of the device during acceleration? Was some sort of brake or physical stop implemented?

9) Correctly measuring the temperature and keep it under control at all times are crucial in the experimental design that makes the core of this thesis. In particular, to best interpret the experimental results, it is necessary to know the temperature on the slip surface. This is

challenging to implement without disturbing the shearing process itself. What is the opinion of the candidate? How close could the measurements be made or, alternatively, how could the temperature of the shear zone be estimated?

10) The temperature of the environment surrounding the device also can affect the experiments. Placing the device in an air-conditioned (temperature and humidity-controlled room) seems necessary but, even so, temperature oscillations may occur. For the most sensitive phases of the creep experiment, I feel even the presence of a person in the room, or a computer that goes on or off, or other devices where experiments are ongoing, can potentially affect the experiment. Has the candidate thought about this, and what is the suggested solution? Despite other limitations, a device with a servo-controlled motor would not have required human intervention to increase/decrease the loads…

11) In the experiment shown in Fig. 12 (Chapter 8), the increase in temperature seems to have occurred quite rapidly in the first two pulses, while in the third try a stepwise increase in temperature was imposed. Still, each increase occurred over minutes (so it seems, but the scale should have been stretched) and perhaps this is fast, and the observed response is ascribable to a sudden increase in pore water pressures. In fact, if a high temperature is maintained for a while, creep displacements stop. What does the candidate think can be an appropriate rate of heating/cooling in consideration of the properties of the tested soil, to ensure drained conditions throughout the experiment? How can this rate be calculated?

12) As a final question, going back to the already mentioned issue of the upscaling, I invite the candidate to discuss the relevance of temperature oscillations in the creep displacements of slow-moving landslides. The candidate's investigation clearly aimed at understanding the shear-zone response, but at the depths of common landslides the temperature may vary very little during the year. Shouldn't research perhaps focus on more shallow soil, such as that forming the first couple of metres of landslide bodies, which is most affected by atmospheric changes?

Recommendation

In summary, after carefully reviewing the thesis submitted by Mr. Mladý, I am convinced to recommend him for the award of the Master's degree. The thesis presents original and creative work which was executed with high commitment and enables further scientific research. Although only preliminary results were presented, I am confident of the candidate's commitment to validating and building upon these results in his coming activities as a doctoral student. I believe the skills and creativity demonstrated in this thesis work will be an asset to Mr. Mladý's career, not only as a researcher but also as a professional engineering geologist, in a context where attention to detail and knowledge of experimental soil mechanics are precious.

With my best regards,

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