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Developing Soft Soil Engineering Skills Using “Class B” and “Class C” Predictions

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ABSTRACT: The calculation of one-dimensional consolidation settlement is a classic geotechnical problem that involves many steps with associated judgement. To give students an opportunity to develop soft-soil engineering skills, we developed a coursework assignment with “Class B” and “Class C” type of predictions of a test embankment on soft clay, starting from real data. “Class B” predictions allow students to deal with uncertainty in input data, while “Class C” predictions enable the students to appreciate the main sources for errors in their analyses. In this paper, we describe the assignment, and the changes made over the course of three years. Furthermore, we analyse the results for selected student cohorts and compare them with the predictions by professionals. The results show that accurate consolidation analysis is not trivial. It is encouraging though that many of the students performed as well as the professionals.

Keywords: soft clay, consolidation, embankment, Class C prediction, Asaoka’s method

1 Introduction

The calculation of one-dimensional (1D) consolidation settlements is a classic geotechnical problem, which is included in every geotechnical engineering textbook and syllabus. Consolidation analyses are particularly important in areas with extensive deposits of soft soils. It is most often embankments for linear infrastructure, e.g. roads, railways, flood protection embankments and tailing dams, for which the analyses of the consolidation settlements are relevant. The problem of consolidation under embankment loading can be considered as a 2D plane strain problem, which is often simplified to 1D, considering vertical settlements only. For preliminary design, and design in rural areas with no sensitive structures in the vicinity of the planned embankments, 1D analyses often suffice.

One-dimensional consolidation analyses for a real embankment involve many steps with assumptions and judgment that are subjective. The latter is not apparent from most textbooks. Assuming the site investigation and laboratory testing have been planned appropriately, and the necessary data are available, there are several steps in 1D consolidation analyses. These include e.g. dividing the compressible deposit into representative layers (initially based on index properties, further refined based upon other laboratory and site investigation information prior geological knowledge), identifying the level of the water table and drainage conditions, determining the relevant model parameters from laboratory test results, calculating the initial stress distribution and the stress increment from the embankment loading as a function of depth, calculating the total consolidation settlement, and finally the rate of settlement. Each stage introduces subjectivity, uncertainties and possibilities for errors. In particular, the interpretation of model parameters from the laboratory test results benefits from experience on similar soil conditions.

For the reasons above, we developed a coursework assignment that gives the students an opportunity to develop soft-soil engineering skills using “Class-B” and “Class-C” type of predictions. “Class B” predictions are blind predictions made during construction with available data, with no knowledge of the field measurement results, while “Class C” predictions are improved predictions with the aid of field observations. “Class B” predictions allow the students to deal with uncertainty, while “Class C” predictions enable to understand the main sources for errors in the analyses (Lambe 1973). In the following, we introduce the case (additional materials can be made available electronically upon request by interested instructors), analyse the results for selected student cohorts, and describe the changes we made over the three years in question. Finally, we compare the predictions by the students with the "Class A" predictions by professionals, made before the construction.

2 Background

The starting point for 1D consolidation analyses is oedometer test results. The way 1D consolidation tests are performed, however, differs from country to country. Most common are Incremental Loading (IL) oedometer tests, which can provide the parameters needed to make predictions that match the field measurements reasonably well. However, the way the load steps are chosen for IL test, the methods for sampling, as well as the quality of sampling and testing may vary. In addition, in some countries, such as Sweden, settlement analyses are largely based on continuously loaded oedometer tests (generally much faster than IL tests), referred to as Constant Rate of Strain (CRS) tests. As only the rate of displacement is controlled, the true strain-rate (by strains here we mean natural strains) increases during the CRS test, and it also takes time for the system to ramp up to the target displacement rate. The higher the strain-rate, the higher the apparent preconsolidation pressure. Thus, the preconsolidation pressure needs to be somehow corrected for strain-rate effects, to yield values that are similar to those from IL tests. The locally derived corrections, such as those used in Sweden (see Sällfors 1975), cannot be generalised for all clays, because the strain-rate susceptibility of clays varies depending e.g. on sensitivity and organic content. Due to the effects of aging (see e.g. Bjerrum 1967) and cementation (e.g. Leroueil & Vaughan 1990) most natural soft soils are lightly overconsolidated, and thus preconsolidation pressure is an important parameter. Finally, the methods for calculating the magnitude of the consolidation settlement (i.e. how to represent the stress-strain response) also vary from country to country.

The rate of consolidation is often calculated with Terzaghi's (1925) 1D consolidation theory, accounting for the distribution of excess pore water pressures by Terzaghi & Fröchlich (1936). The increasing internationalisation of the student body necessitates that geotechnical education covers more than just the locally used methods for consolidation analyses. The students need to appreciate that there are multiple ways of doing the analyses, and furthermore there are a lot of uncertainties involved when the theories developed for "ideal soils" are applied to natural soft soils. Geotechnical textbooks rarely present real soil data, and in the examples included, the model parameters are derived from "ideal" data, which fully conform with the theories used. Examples of settlement analyses tend to use fixed values for model parameters, giving the misleading impression there is one exact, "correct", solution. Issues like sample disturbance, and its effect on the measured stress-strain curve, and the apparent preconsolidation pressure, are addressed in only a few textbooks, such as Barnes (2016).

It is important for future geotechnical practitioners to understand how the theories are applied to real data, and also to appreciate how error-prone, and inaccurate, the consolidation analyses can be in practice. The settlement calculation competition for the Haarajoki test embankment in Finland (Lojander & Vepsäläinen 2001), and most recently the Ballina embankment challenge in Australia (Kelly et al. 2018), demonstrate that even if the analyses are done by the most experienced academics and practitioners, the errors in the predictions of consolidation settlements can easily be $\pm$20%. The errors can be even larger, if the practitioners are not used to dealing with sensitive clays, which practically exhibit "a collapse settlement" when the preconsolidation pressure is exceeded. This was the case in Haarajoki test embankment. Furthermore, Kelly et al. (2018) show that the scatter is most significant for "Class A" predictions. Field monitoring can significantly improve the predictions during construction time.

The natural clays found in Scandinavia were formed during and after the last Ice Age, when large parts of the Northern Hemisphere were covered with glaciers. The glacial meltwaters, heavily laden with sediments, discharged to glacial lakes and seas. In particular, the fine-grained sediments from the Yoldian and Littorina sea stages of the Baltic Sea region (see Björk 1995), were deposited in brackish or very salty water, which led to an open structure with large water contents. These deposits subsequently surfaced from the sea due to the isostatic uplift and were exposed to leaching. Consequently, these post-glacial clays have an open structure that is now metastable, and often exhibit significant sensitivity. As a result, their response under one-dimensional loading does not follow the response typically shown in textbooks. Figure 1 combines the results from multiple IL oedometer tests of a sensitive Finnish clay, Vanttila clay, plotted in semi-logarithmic scale. On the left in Figure 1 we have plotted the vertical effective stress vs. void ratio e, and on the right the creep index (secondary compression index) $C_{\alpha e}$ (defined as $-\delta e/\delta \log t$, where t is time). The black stars correspond to the intact samples of natural clay, taken with piston samplers, and the red squares are the results for the same clay after remoulding at the same water content, and subsequent reconstitution to the in-situ stress level. The sensitivity (S_t) of the clay is above 50 (Karstunen & Koskinen 2008). Only the reconstituted samples exhibit a constant compression index C_c as found in textbooks. The apparent C_c values of the natural clay are changing with the stress level, and the same applies to the creep index. In contrast, the swelling/recompression index C_s is approximately the same. The C_c values are the highest just after yield (see dashed black line in Fig.1), and this coincides with the effective stress level for the highest apparent creep rates ($C_{\alpha e}$ values in Fig. 1). Thus, when performing the consolidation analyses of natural clays, it is important that the oedometer stiffness used corresponds to the appropriate stress range. In practice, if C_c is used, the value should typically be determined from the steepest part of the slope, just after the yield (as indicated by the dashed black line in Fig.1). The consequence of the large C_c value is that the results of the 1D settlement analyses are very sensitive to the value of the apparent preconsolidation pressure, which can also be affected by sample disturbance.

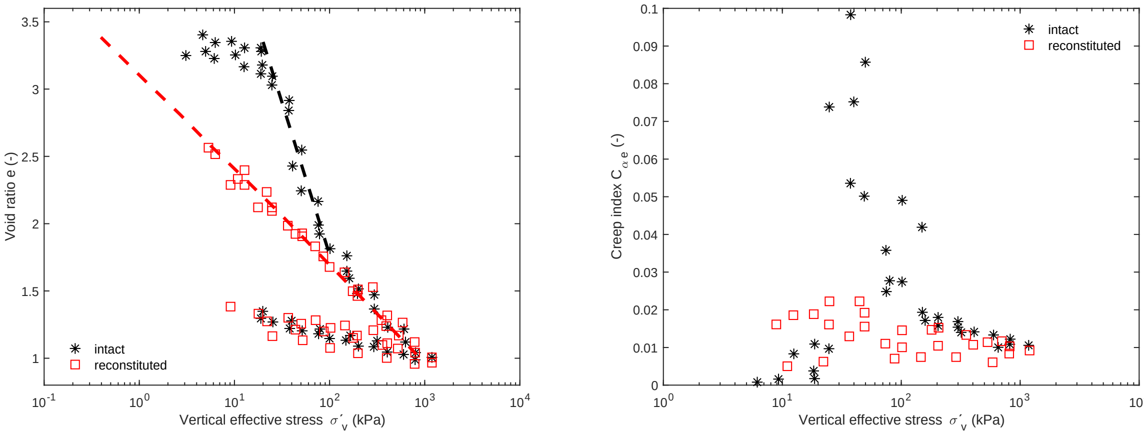

Figure 1. 1D response of intact and reconstituted Finnish sensitive clay (data from Yin et al. 2011)

The coefficient of (vertical) consolidation, c_v, also varies with effective stress level, with the lowest values just after yield. Particularly for layered deposits, the c_v values in the field can be magnitudes higher than the values measured in the laboratory, see e.g. Baligh & Levadoux (1986) and Leroueil (1988). Furthermore, IL tests usually suggest systematically lower values than CRS tests. Combined with uncertainties in the drainage conditions in the field, consolidation analyses are not simple. Thus, we wanted to develop a coursework assignment where we provide students with field monitoring data, as one would get during construction of an infrastructure project, in addition to laboratory data. This would enable the students to have a pedagogically important feedback loop, which hopefully highlights the most likely sources for the errors in their predictions, whether it is their prediction of the total settlement or the rate of settlement.

3 Implementing a design project

3.1 Purpose of the design project

Our pedagogical vision is to educate students in the relevant theories and methods for soil mechanics and geotechnical engineering, with the ability to confidently apply these in a practical context, using real data. Given our geographical location, the focus is on soft natural clays. The coursework assignment, involving consolidation analyses of a real embankment, was developed as a response to the student expectations: the course evaluation in 2014 suggested that the Year 4 MSc course was too theoretical and abstract. The students wanted to have the opportunity for a realistic application of their knowledge, similarly to our BSc level courses. Our expectation was that by starting from real experimental data and adding a feedback loop enabling the students to assess where they might have gone wrong, the students would develop valuable skills in soft clay engineering.

The coursework assignment was run in 2015-2019 at Chalmers University of Technology, Sweden, combining “Class B” and “Class C” predictions. Initially, the assignment was included in an optional Year 4 MSc course taken by students from two MSc programmes: (1) Infrastructure and Environmental Engineering and (2) Structural Engineering and Building Technology. The typical class size was about 100 students. In 2017, as part of our new degree programmes (i.e. BSc in Civil Engineering and MSc in

Civil and Environmental Engineering), the assignment was moved to Year 3, to an optional course Hydrogeology and Geotechnics, with about 70-80 students. In both cases, the Chalmers students had the knowledge from Year 1 Engineering Geology (7.5 ECTS) and Year 3 Geotechnics (7.5 and 6 ECTS, in the "old" and "new" degree programme, respectively), taught in Swedish. Year 3 Geotechnics covers the CRS test-based consolidation settlement calculations used by industry in Sweden. The MSc students had much more variable background: about 50% were Chalmers students, 33% Erasmus/exchange students from Europe and 17% international students from all over the world, the latter including some students with no geotechnical courses as part of their previous education. With these few exceptions, the concept of consolidation settlements of clays is known to all students.

3.2 Selecting a case study

We wanted an embankment on soft sensitive clay without any ground improvement, with access to site investigation data and laboratory data in a digital format, so that we could supply the data in a format that was suitable for our students. Furthermore, there had to be a sufficiently long time-series of settlement measurements enabling a feedback loop. These requirements were satisfied by the Haarajoki test embankment in Southern Finland, which was built in 1997 by the Finnish Road Administration to evaluate the long-term settlements and the changes in the undrained shear strength as a function of time (Vepsäläinen et al. 2002).

Haarajoki embankment has been used to test the accuracy of different constitutive models and modelling approaches (e.g. Yildiz et al. 2009; Amavasai et al. 2017) and was also used for an international "Class A" prediction competition (Lojander & Vepsäläinen 2001). The latter involved predictions with conventional methods and numerical methods, considering also a section on vertical drains installed over half of the length of the embankment. Figure 2 shows the results, for the section with no ground improvement, for vertical settlements directly below the centreline (data from Lojander & Vepsäläinen 2001). The predictions are compared with two years of measurements. The best prediction, which is rather accurate, was made by a team with local knowledge. Some participants seem to have included also the immediate settlements. The large scatter in the predictions is associated with inexperience with sensitive clays of some of the predictors (who assumed the soil to be normally consolidated). We were thus curious to see how our students' predictions relate to the professionals, after the guidance we give as part of the lectures and tutorials.

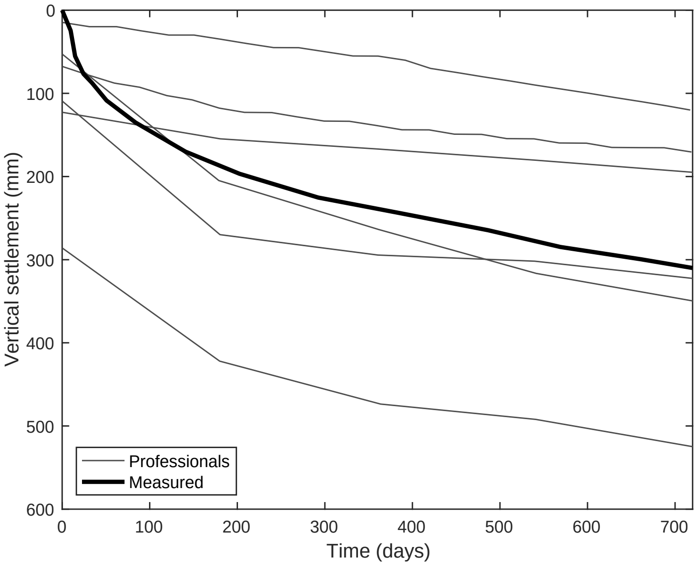

Figure 2. Measured vertical settlements of Haarajoki test embankment and "Class A" predictions made by geotechnical professionals (data from Lojander & Vepsäläinen 2001)

Haarajoki test embankment (Fig. 3) about 45 km North-East from Helsinki was built on a deposit of about 20 m of soft sensitive clay about 45 km North-East from Helsinki. At the bottom, there is about three meters of highly permeable glacial till (sandy moraine) on top of the bedrock, and just below the surface there is a 2 m thick dry crust, linked with the seasonal variation of the groundwater table. Piezometer measurements on the site suggest that on average, the water table is approximately at the ground surface. The clay has a sensitivity (the ratio of the intact undrained shear strength to the remoulded undrained shear strength) S_t = 25 at the top, increasing to S_t = 50 towards the bottom. The dimensions of the test embankment are given in Figure 3. In total, the embankment is 100 m long, with stabilising berms on both sides. We only consider the part of the embankment (50 m long) on natural clay (i.e. not the section with vertical drains). The test embankment was built over a period of 35 days in multiple steps (see e.g. Amavasai et al. 2017), but given the low hydraulic conductivity, the students are told to assume instantaneous loading. Most natural clays exhibit tendency to creep, and the students are aware of the role of secondary compression. Modelling creep was not explicitly included in the student assignment in order to keep the workload manageable. The creep effects are, however, implicitly included, given the *e* vs. effective stress plots represent the *e* values after 24h, as is the industry practice, rather than at the end of consolidation. The task for the students is to predict the vertical settlement as a function of time in point A, just under the centreline.

Note: Not in scale

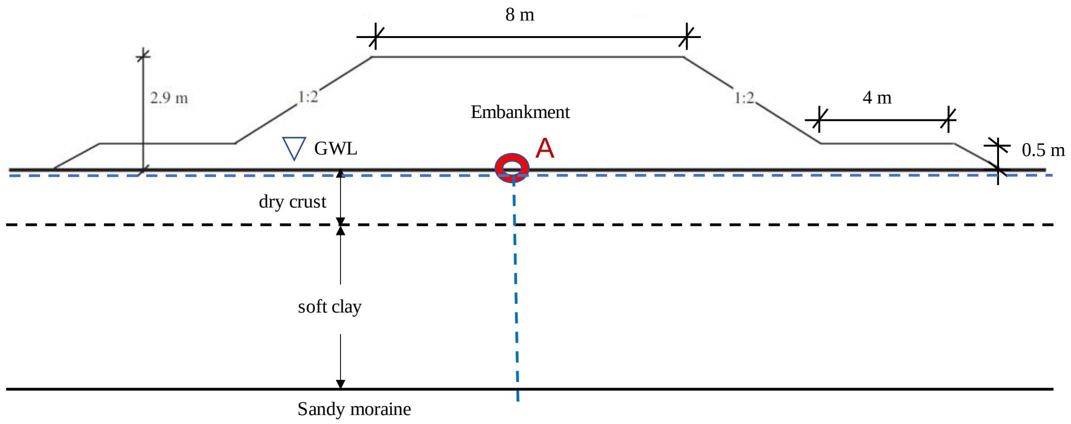

Figure 3. **Simplified cross-section used for settlement prediction (not in scale)**

3.3 Materials provided to the student

The cross-section of the embankment (Fig. 3) was provided to the students by giving them a copy of the actual construction drawings of the relevant cross section. That included the site investigation data, consisting of field vane tests, CPT tests and Swedish weight sounding tests. We also explained how the tests are conducted, and what for. The students were also provided with basic index properties (see e.g. Amavasai et al. 2017), i.e. water content, organic content, undrained shear strength from fall cone, void ratio, unit weight and sensitivity. Based on all these, the students can confirm the approximate symmetry of the problem, estimate the thickness of the dry crust and compressible layer, whilst the data on index properties enables them to divide the soft clay into representative layers for the analyses, to be confirmed by other laboratory data. An example of how to do the layer division was done in the class, using another deposit as an example.

We digitised all laboratory data available to the contestants of the original settlement calculation competition. The students were provided with IL test data (void ratio vs. vertical effective stress) in Excel format for determination of preconsolidation pressures and stiffnesses. The results were also plotted in semi-log scale for direct use. CRS data (plotted in terms of coefficient of consolidation vs. vertical effective stress), see Figure 4 as an example, was provided to reduce the routine work associated with determination of c_v. For the MSc students we provided all data, i.e. 27 IL oedometer tests and 14 CRS tests. For Year 3 students, who also had other course assignments, we reduced the amount of data by selecting only 9 IL tests and 6 CRS tests, effectively cutting out the tests on samples that were deemed to be most disturbed. The project consisted of two parts, as described in the following.

Students were also provided with an Excel template for returning the result. They needed to report the time-settlement curves for circa 1500 days, as well as the estimates for the total settlement, plus justifications, such as the interpretation of in situ stresses, preconsolidation pressure etc. The students were processing the data and doing their analyses in groups of max 3 students. After we got the submissions for Part 1 of the project, we provided the measured settlements at the centreline, and 4 and 9 m off the centreline. We used the 3 years of measurement data available in Vepsäläinen et al. (2002). The measured settlement under the centreline was 370 mm after 3 years. When compared to the estimated final settlement (1200 mm), derived by Länsivaara (2001) using the so-called settlement potential method (including of course also creep and 2D effects), or 2D analyses with the advanced anisotropic creep model Creep-SCLAY1S by Amavasai et al. (2017), this corresponds to a degree of consolidation of around 30% only in terms of settlements. However, in terms of the excess pore water pressure dissipation, the actual degree of consolidation after three years is closer to 60%. So, there is much creep, which means that the assignment is not ideal.

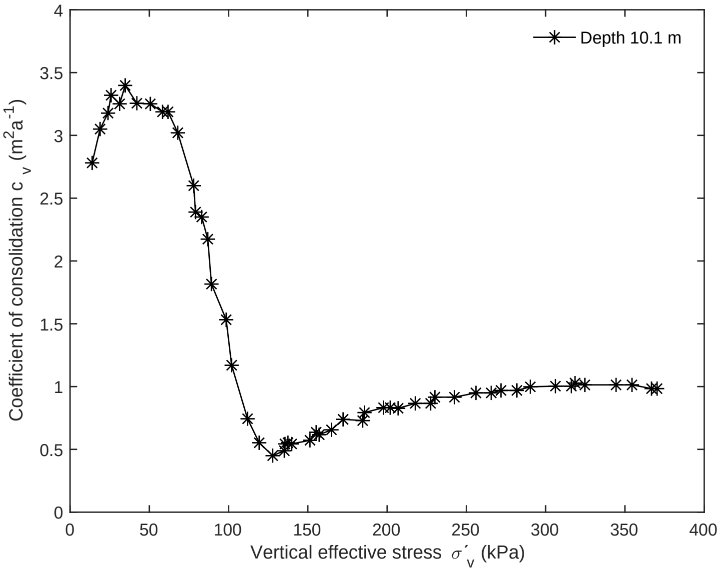

Figure 4. Example of CRS data provided to the students

In Part 2 of the project the students were asked to use Asaoka's graphical method (Asaoka 1978) on the field measurements. The method was introduced in the lectures. Asaoka's method requires field measurements of settlements as a time series, from which settlement values are determined for times t, t+Δt, t+2Δt, etc. The final (total) settlement is estimated by cross-plotting pairs of consecutive settlement values. It is based on the expectation that after a sufficient time, the measurements at two consecutive time steps will be the same. The field value for the coefficient of consolidation, c_v, for the deposit as a whole is calculated from a tangent drawn to the curve in the previously mentioned graph and taking into account the form of the differential equation describing consolidation settlement. With their estimates of (a) the final settlement and (b) the field values of c_v, Asaoka's method enables the students to reflect what (in most cases) had gone wrong in their predictions. According to Länsivaara (2001), Asaoka's method is not the best in a creeping deposit, but the alternative methods that were also introduced in the class are not internationally as well known. In the following, we analyse the "Class B" results for selected cohorts, describe the changes we made, and also compare with the "Class A" predictions by professionals.

4 Results

4.1 MSc cohorts 1 & 2

The students in MSc cohort 1 (in 2015) could use any method they wanted. From 2016 onwards we imposed the settlement calculation method that separates the compression and swelling (or recompression) indices. This requires the determination of the preconsolidation pressure and has thus a better linkage with the Modified Cam Clay (MCC) -type of models the students will use in Year 5 (such as MCC (Roscoe and Burland 1968) and the Soft Soil model in Plaxis FE code). As a first comparison, Figure 5 presents the predicted and measured time series of the vertical settlements directly below the embankment by the two MSc cohorts, i.e. the "Class B" prediction. As opposed to the Class A predictions in Figure 1, now 1483 days (4 years) of measurements are available. Even though two cohorts are shown, for cohort 2 only a third of the data was readily available for plotting.

MSc cohort 1 has a larger number of outliers in the results than MSc cohort 2. The scatter is largely related to the freedom MSc cohort 1 had in selecting their calculation method. The time-series indicate that both the estimated final settlement and the rate of consolidation were highly inaccurate for a large number of students. Interestingly, the most accurate prediction in MSc cohort 1 did not use any equation or derived stiffness properties. Instead, the total vertical strain was determined using, for each layer, the oedometer compression curves closest to the centre of the layer, and the corresponding stress increment at each depth (graphical interpretation) and summing them up for all layers. This circumvents the need for the evaluation of consolidation parameters that are error-prone, and it also was less effort for the students. Most students, however, used one of the methods taught during the course and practised in the tutorials.

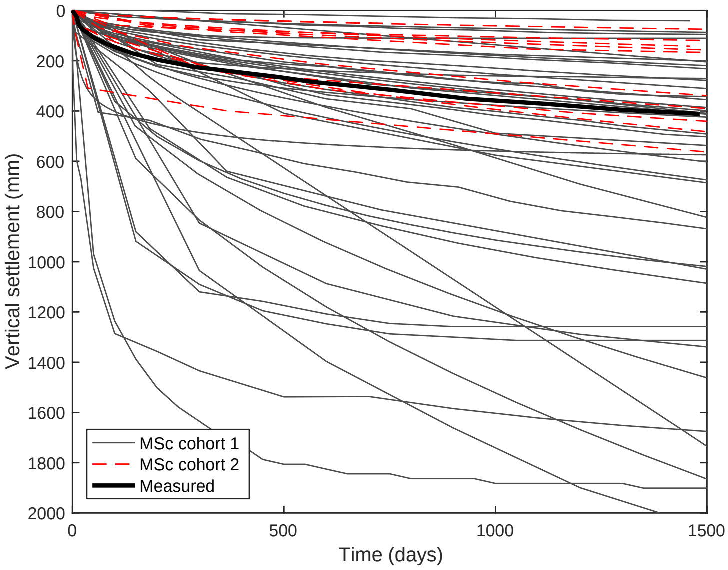

Figure 5. Measured time series for the vertical settlements directly below the embankment at the centreline and predictions made by 2 cohorts of students in the MSc programme at Chalmers

For Part 2 of the project, 1st cohort of MSc students really struggled with Asaoka's method, which included two different back analyses: (a) amount of settlement and (b) rate of settlement. Thus, for the following years, the lecture on Asaoka's method was complemented with a hands-on tutorial example, using the data from Skå-Edeby test embankment (Larsson 2007).

As already mentioned, following the first year, and in order to have alignment with the courses to come, the MSc cohort 2 was instructed to use only the method based on C_c, C_s and preconsolidation pressure. This helped to align course materials, related to the geological and anthropogenic processes affecting the apparent preconsolidation pressure in natural soft soils, with the assignment. Furthermore, it transforms the problem-based nature of the assignment into a project-based element. These changes reduced the scatter (as seen in Fig. 5), but also introduced an underprediction bias in the results, as discussed in the following paragraph. For further analyses the results are re-plotted in Figure 6 as a histogram, which plots the frequency of occurrence for 10 bins and three data series: MSc cohort 1 & 2 and the BSc cohort 1. All available data for the settlements at the end of the measurement period have been processed by subtracting the measured value, so the deviations from measured are shown in Figure 5. A time window between 1483 and 1500 days has been used to determine this end value.

The most striking finding is that prescribing the method resulted in a systematic underprediction of the settlements by MSc cohort 2. Examination of the reports indicates that this underprediction is linked in most cases with defining C_c as the average for the entire effective stress range, and/or overestimation of the apparent preconsolidation pressures. Furthermore, it shows the rather close predictions of almost half of the MSc cohort 1 falling within +/- 200 mm or +/-50% of the measured settlements (the bin width is 200 mm).

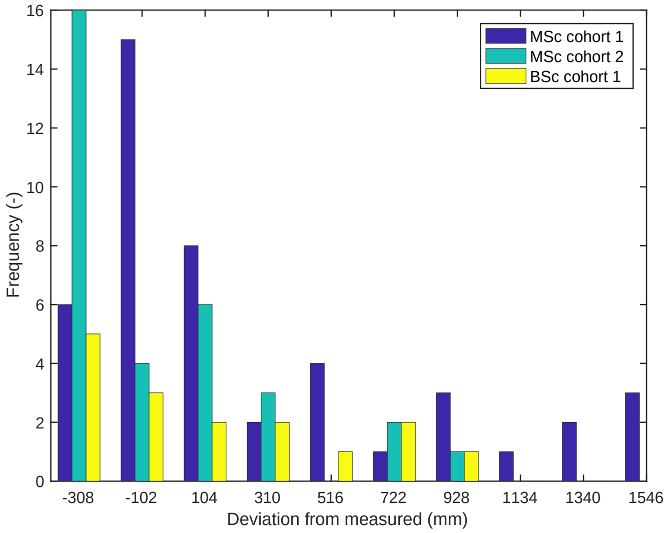

Figure 6. Deviation between predicted and measured (411 mm) vertical settlements below the embankment at the centreline after 1483-1500 days

The data for the results of Part 2 of the assignment, i.e. the use of Asaoka's method to improve the initial predictions, was much harder to analyse (and to mark). In short, the mediocre students simply 'fitted' the data by random alterations of the parameters, and the good students left things unchanged. This was partly related to our seven-week intense teaching periods, which means that the students run out of time at the end of the course. In the second round for MSc cohort 2, after introducing a separate additional tutorial on the use of the method, the results of Part 2 were more reflective, as was our intention. When in industry, the students need methods for assessing how consolidation progresses in the field. Asaoka's method is only one of the methods taught in the course that can be used for this purpose. The pedagogical implications for the observations will be further discussed in Section 5.

4.2 BSc cohort 1

Figure 6 already indicates that BSc cohort 1 performed similarly to MSc cohort 2, with emphasis on under- rather than overprediction, and a much narrower spread than MSc cohort 1. In that aspect, reducing the available laboratory data seems to have similar effect for both MSc 2 and BSc 1 cohorts.

Studying the time series in Figure 7 may give the impression that uncertainty arises in the determination of the coefficient of consolidation (from averaging CRS data for each depth over the full profile, and/or from the assessment of the drainage conditions at the field). To further evaluate this interpretation, a histogram of the predicted final settlements is presented in Figure 8. Given the slow processes, there is no measurement data available for this estimate. As already mentioned, the best estimate for the final settlements is 1200 mm (Länsivaara 2001; Amavasai et al. 2017). Many students are surprisingly close to this magnitude (1200 mm ± 100 mm). The fact that the estimate for the magnitude of the settlement is on average reasonable, reinforces the interpretation that establishing an estimate for the coefficient of consolidation, as an average for the whole deposit is difficult. This cannot solely be attributed to the students, as it is an inherent limitation of the methods used. Santamarina (2015) argues for the use of numerical methods that supersede the simplified single point analyses advocated by most teachers and textbooks.

5 Pedagogical reflection

In addition to the industry's need for graduates able to perform engineering designs with natural soils, as described in the introduction, there were pedagogical motivations for the coursework development as well. First, the course needed changes to improve the engagement of the indifferent middle group, i.e. the efficient students who design their study to pass the course with minimal effort, maximum effect in terms of a grade and minimal retention of knowledge (e.g. Marton & Säljö 1976). A teaching instrument that brings the students closer to the engineering practice will help (and was requested by students in prior years). The most likely tool for this seems to integrate a problem-based learning element in the course. The expected outcome is that, when attained, problem-based learning should help students to have a longer retention of their knowledge and an idea of the relevance of the material to the engineering practice (Beers & Bowden 2005). Furthermore, project work will help the student understand what real engineering is about, i.e. without the certainties that you do not find in a textbook assignment.

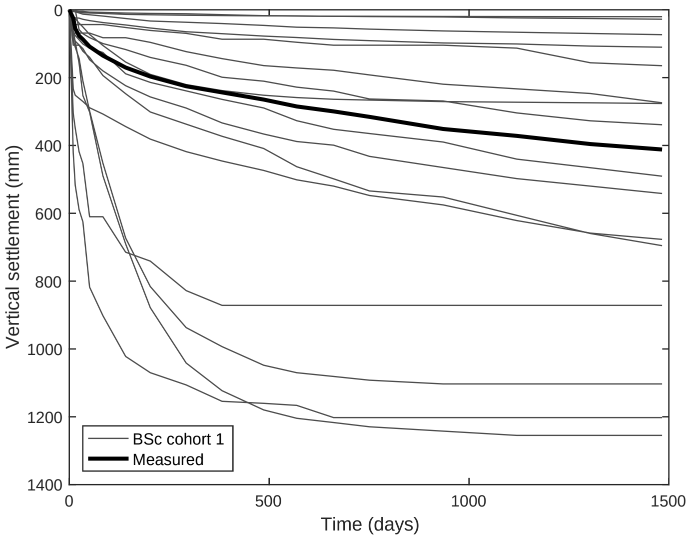

Figure 7. Measured time series for the vertical settlements directly below the embankment at the centreline and predictions made by Year 3 BSc cohort at Chalmers

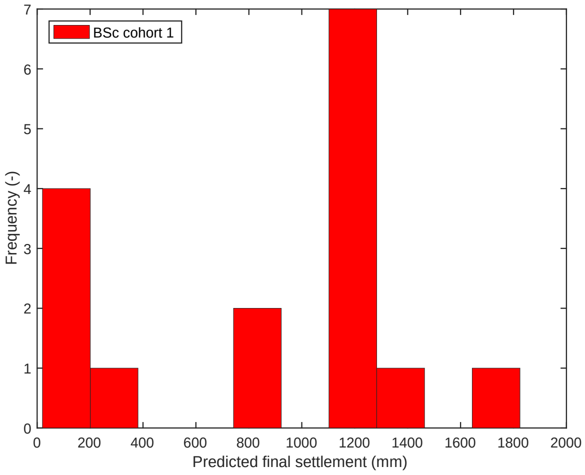

Figure 8. Histogram of predicted final vertical settlements directly below the embankment at the centreline by Year 3 BSc cohort at Chalmers

The first implementation of the project work, i.e. MSc cohort 1, proved to be closer to problem-based learning, where the students develop knowledge during the project. Not only is this hard for an engineering project, it also requires students to be trained for project-based learning: independence, group work, interpersonal skills, etc. (Woods 1996). In conventional Civil Engineering programmes, such as the one at Chalmers, students are not explicitly trained to develop such skills. Furthermore, there was not as much alignment between the lectures, tutorials and the activities in the prediction project as would be pedagogically effective (Biggs 2014). It turns out that for complex tasks in engineering education, which the project inevitably represents, problem-based learning is unsuitable (Perrenet et al. 2000; Mills & Treagust 2003).

In the subsequent implementation of the project, more guidance and prior knowledge was developed following constructive alignment practices, linking taught material and schedule with project deliverables, as well as adding an additional tutorial on Asaoka’s method. Whilst this reduced the scatter in the results (MSc cohort 2), it introduced a bias towards underestimation. This could be due to us selecting tests with the best sample quality. Prior knowledge and experience seem to have little effect on this result, when comparing MSc cohort 2 and BSc cohort 1. Prior knowledge assumes that all knowledge is retained, so that MSc students have a deeper understanding, but this is not necessarily the case. It should also be noted that the MSc students were a rather heterogeneous group, compared to the BSc students who all had identical geotechnical background. Hence, misconceptions students have developed on fundamental mechanisms in other courses might have influenced the results (Clements 1982; Pantazidou 2009).

A potential misconception lies in the understanding of the serviceability limit state (SLS) design (the prediction project), as opposed to the ultimate limit state (ULS) design the students are most familiar with. It is hypothesized that using conservative best estimate values for the undrained strength in ULS design (taught in prior courses) is leading to underestimation of the compressibility. A low value of C_c leads to lower predicted settlements, which is counterintuitive for students used to deal with Young's moduli in other courses. The same applies for the coefficient of consolidation: the students underestimated rate of consolidation, often by choosing c_v values corresponding to the normally consolidated range, and hence the predicted settlement-rate was underestimated.

Feedback is essential in teaching and engineering practice. Due to lack of understanding and context, the students (and engineers) respond poorly to feedback (Sadler 2010). The intention of the "Class C" prediction element in the project was to incorporate feedback in a non-judgemental manner. Asaoka's method (Asaoka 1978) enables identification of the possible source of the error by enabling the calculation of (a) the final amount of settlement as well as (b) the rate of settlement in the field (that also includes the effects of creep in the measurement data). Unfortunately, the students who predicted the outliers also struggled with Asaoka's method and were hence rather clueless. In contrast, due to the limitations of Asaoka's method for our data (i.e. presence of significant creep) the students with a good initial prediction had no obvious source of errors. This is perhaps something that could be overcome by peer review.

Finally, all predicted time series have been compiled in Figure 9. Clearly, limiting the method to be used for the settlement calculations takes out some of the outliers in the over-prediction side. Encouragingly, the scatter in the predictions by the MSc cohort 2 is very similar with those of the professionals, and the same applies to the majority of the BSc students.

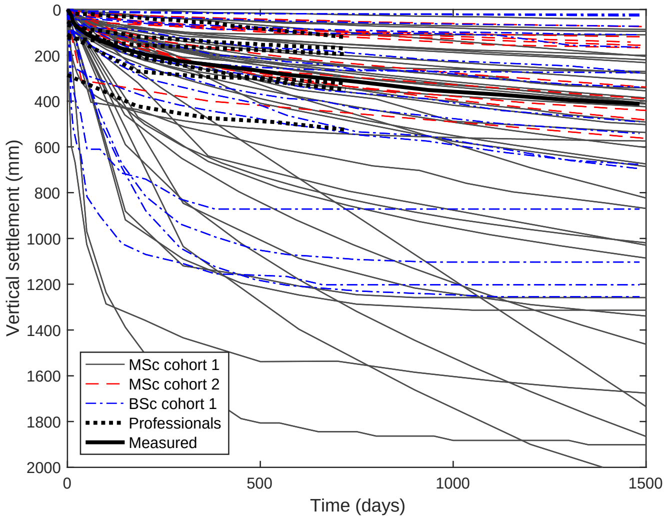

Figure 9. Measured time series for the vertical settlement directly below the embankment at the centre line and predictions by professionals and students

6 Conclusions

Geotechnical engineers have to deal with natural soils and the uncertainties associated with the formation history, design methods and available data from the laboratory and the field. Adding a "Class B & C" prediction project in the course is a suitable instrument to teach these notions, whilst engaging the students in active learning. The current paper demonstrates that creating a successful project is far from trivial. Depending on the degree of the alignment between the lectures, tutorials and the project work, the amount and quality of the data provided, prior conceptions and the quality of the feedback mechanisms, results may vary. When comparing all predictions together, it is comforting though that most students performed as well as the professionals.

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