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An Example of Teaching Slope Stability from True Case Histories

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ABSTRACT

The use of case histories in classroom mainly involves an inductive teaching approach. This paper discusses the intrinsic advantages and possible drawbacks of such an inductive approach. More specifically, the paper illustrates an example of teaching the class of "slope stability" based on such methodology. The class takes place at the University of Pisa in the second tier degree of Civil Engineering of Infrastructures. The inductive teaching approach is very popular in the British/American Higher Education system. On the contrary it is not so popular in Latin countries like Italy. In order to make more clear the comprehension of this paper to the potential readers, information on the Higher Education system in Europe and specifically in Italy is also given.

INTRODUCTION

Prof. Ralph Peck introduced in 1956 the use of geotechnical case histories to teach graduate students problem solving and technical communication skills (Rogers 2008, Peck & Ireland 1974). According to Rogers, the graduate students were assigned the role of being the "ersatz consulting board". Peck would present the essential elements and facts of a particular case, playing the role of the project geotechnical engineer. Some of the case histories used by Prof. Peck are reported in Rogers (2008).
Such an inductive teaching approach is very popular in the British/American Higher Education system, especially in the technical/scientific study area. The approach is also well developed in many East-Asia countries.
On the contrary it is not so popular in Europe where very different Higher Education systems exists in different countries nonetheless the so – called Bologna Process.
The **Bologna Process** is a series of ministerial meetings and agreements between European countries designed to ensure comparability in the standards and quality of higher education qualifications. It is named after the place it was proposed, the University of Bologna, with the signing in 1999 of the Bologna declaration by Education Ministers from 29 European countries.
From a practical point of view, the Bologna process has introduced:

- the two tiers degree, equivalent to Bachelor + Master (eventually followed, after the Master degree by the Doctorate)
- the European Credit Transfer System (ECTS).

According to the ECTS, one credit should correspond to 25 study hours including individual study and the time spent in the classroom.
In order to appreciate the differences among different Higher Education systems in Europe, it is very instructive to consider the few data summarised in Table 1. It is quite evident that Scientific Subjects (Matemathics, Physics, etc.) represent a high to very high percentage of the total credits, in some countries and especially in Italy, while the percentage of activities carried out by the students themselves (i.e. thesis, practical placement or study of case histories) represent a high percentage of total credits mainly in UK and Ireland.
More information on the Higher Education system of Civil Engineering in Europe is available from EUCEET 2011. EUCEET (European Civil Engineering Education and Training) has been the acronym of an European Network (supported by the European Union) and now is a no – profit association.

Table 1. Weight of different areas as a percentage (average values) – First Tier degree or integrated Master.

Country (Universities)	Scientific	Civil Engineering	Other Engineering	Other	Student activity
Romania (Cluji Napoca, Iasi, Timisoara, UTCB)	14	62	8	8	8
UK (Imperial College)	14	52	4	2	28
Italy (Pisa, Politecnico	31 - 33	41 - 47	10 - 20	3 - 10	2 - 3

Milano)					
Spain (Cantabria, Barcelona)	17.5	62.5	7.5	7.5	5
Belgium (KU Leuven)	41	35	5	8	11
Poland (Silesian University of Technology, Gliwice)	11.5	59.3	3.1	9.4	18.7
France (ESTP)	14	46	20	10	10
Budapest University of Technology and Economics	19	54	0	14	13
Ireland (University College Dublin)	23(CE) [1] 15(SEA)	50(CE) 45(SEA)	20(CE) 18(SEA)	2(CE) 3(SEA)	5(CE) 18(SEA)
Czech Republic, CTU in Prague, Faculty of Civil Engineering	20,5	58	10,5	4,5	6,5

Scientific = Mathematics, Physics, Chemistry; Civil Engineering (Structural Mechanics, Structural Engineering, Geotechnics, Hydraulics, Roads, Transportations, etc.); Other Engineering (Electrotecnics, Technical Physics or Physics of Building, etc.); Other (Economics and law, etc.)

COURSE DESCRIPTION

Geotechnics is taught at the University of Pisa in the Courses of Civil and Building Engineering. More specifically, as far as Civil & Building Engineering is concerned, the following Courses are established:

- Civil & Environmental and Building Engineering (first tier degree);
- Civil Infrastructures Engineering – CIE (Hydraulics and Transportations Engineering) (second tier degree);
- Civil Constructions Engineering – CCE (second tier degree)
- Building Engineering & Architecture (five year integrated course)

Within the above Courses the following subjects related to Geotechnics are given:

- Soil Mechanics – 9 credits – 90 teaching hours (first tier degree);
- Geotechnics 9 credits 120 teaching hours (five year integrated course);
- Slope stability and retaining walls 6 credits – 60 teaching hours (CIE second tier degree)
- Foundations 6 credits – 60 teaching hours (CCE second tier degree)

The class of "Slope stability and retaining walls" has been offered for the first time in academic year 2010-2011. It deals with the following topics:

- Soil investigations
- Soil hydraulics (steady and non-steady flow)
- Stability of natural and man-made slopes (limit equilibrium method, Newmark - displacement based approach)
- Design of rigid retaining walls
- Design of flexible retaining walls
- Ground anchors and temporary supports

Slope stability analysis is mainly aimed at the geotechnical design of road and river embankments. Locally, the main causes of failures of these embankments are:

- Piping or Seepage
- Excessive settlements of underlying organic soils
- Failure of underlying soft soils (recent lacustrine deposits, mainly consisting of clayey silts).

The case study of a flood-plain bank[2] overlying a very soft organic soil has been selected for didactic purposes. An aerial photograph of the site vicinity is shown in Figure 1. Figure 2 gives the cross section of the flood-plain bank, which is 5 m high and about 500 m long. The bank exhibits several failure surfaces on both sides, as indicated in Figure 1. The failure surfaces seem circular even though there is no apparent evidence of their toe. The bank was constructed many years ago and has been continuously affected by similar problems. The Author has acted as consultant for this geotechnical structure, planning the investigations (boreholes, CPTU, laboratory testing) and carrying out stability analyses by the limit equilibrium method (block analyses and Janbu method) and Finite Element Method (FEM) analyses (Plaxis 2D, 2011). As for this case, it was possible to assess that the main cause of observed instabilities was the excessive settlement of the soft layer. This aspect was clarified through the use of FEM analyses. Students are not instructed to use FEM. Their training mainly concerns the use of the limit equilibrium method with uncoupled seepage and settlement analyses.

As already mentioned, the subject is taught in 60 hours of lectures and practical training (in total 5 hours per week). In addition, students can contact either the instructor (the author of this paper) or two Teaching assistants during the period for additional explanations. The allotted time for these additional explanations is four hours per week for each of the three teaching staff involved. The students are asked to address the case history described in this paper and another two simpler

[1] Both programmes are accredited by Engineers Ireland; CE = 4-yr, Honours Bachelor of Engineering in Civil Engineering; SEA = Structural Engineering with Architecture, a "Bologna 3+2" programme leading to the BSc in Engineering (3 yrs) and Master of Engineering (2 yrs).

[2] The term flood-plain bank is used to indicate an earth embankment for the hydraulic protection of the territory, constructed far away from the usual river bed.

problems (steady flow under a diaphragm wall and design of a flexible structure in a seismic area).

BRIEF DESCRIPTION OF THE CASE HISTORY

The students are informed about the fact that the bank really exists and of the existence of failure surfaces on both sides of the bank.
The available information given to the students consists of the following:

- Two boreholes with undisturbed sampling (Shelby and Osterberg types), carried out from the top of the bank. Figure 3 shows information from one of the two boreholes.
- Six CPTU with few dissipation tests (3 tests were carried out from the toe of the bank, another 3 tests from the top of the bank). Figure 4 shows the results from a CPTU test conducted at the toe of the bank.
- Laboratory testing (classification, triaxial, odometer tests). Figure 5 shows results from one odometer test (from about 10 m depth – borehole S1, sample C3).
- Location in plant of the in situ investigations.
- Geology of the area.
- Cross section of the bank.
- Maximum water level (river side).

As for the geological information, the bank is located in a plain delimited N – E by the buttresses of the Apuan Alps and S – W by the Tirrenian sea. In the study area the plain is filled from top to bottom by recent fluvio-lacustrine and silting deposits (depositi di colmata is the local name) followed by recent peat lacustrine deposits.
During a flood, it is assumed that the maximum water level (river side) reaches the top of the bank.
Some samples are of good quality and give useful data; other samples are of very poor quality and therefore can be used only for classification purposes. All the information, including test location, is available at www.ing.unipi.it/geotecnica (folders Didattica [Educational] / Scavi rilevati e Opere di sostegno [Excavations, Embankments and Retaining Structures] / Esercitazione 2). Readers interested in the details can access the information trough the website (Text is in Italian).
The students are asked to answer the following questions:

- which problems could be encountered in constructing a 5 m high bank of a given geometry? (The bank geometry corresponds to the actual one.)
- what would you suggest in order to overcome the potential problems?

The students have already covered in previous classes the topics below:

- shear strength of soils;
- limit equilibrium method for slope stability analysis;
- steady flow through earth banks;
- 1D Terzaghi consolidation theory;
- radial consolidation through vertical drains;
- consolidation settlement by means of the odometer or elastic method.

In order to answer the questions, students are asked to firstly define a geological model (simplified stratigraphy) and a geotechnical model (mechanical and hydraulic parameters of main soil layers). In order to analyze uncoupled slope stability and steady flow, it is suggested students use the educational version of SLOPE/W (GeoStudio 2007).
The definition of a simplified stratigraphy involves the use of redundant data (2 boreholes and 2 CPTU). CPTU are interpreted using an educational version of CPeT-IT (2011). Stratigraphic logs are sometimes too detailed and CPTU are more useful for discriminating different soil types. The student should be able to recognize that:

- the existing bank and the underlying layer of sandy silt have similar characteristics. This layer is quite heterogeneous with some stiff sand layer
- the peat layer is located between 9 and 15 m below the top of the bank
- below the peat layer there is a medium stiff sand layer
- layering is essentially horizontal
- ground water table (GWT) is 1 m below the bottom of the bank.

Compressibility and permeability parameters are inferred from odometer test results. As for the permeability, the students should recognize that those inferred from dissipation tests during CPTU are much higher than those obtained from Odometer tests as a consequence of the fact that thin lenses of silts interbedded between peat layers may facilitate the horizontal drainage. Odometer curves are interpreted in order to define the OCR of the first two layers. Some odometer test results are not usable because of the poor quality of the samples. An example of odometer curve obtained from a poor quality sample is reported in Figure 6. Figures 5 and 6 also include the pictures of the respectively samples.
Interpretation of triaxial test results is not requested and students can directly use the fitting parameters given in the available documents. It is requested to determine the undrained shear strength of peat layer and the friction angle of the sand layer from CPTU test results using CPet-IT (2011).
Figure 7 summarizes the geotechnical model obtained by many students. A simplified geometry of the bank has been considered.

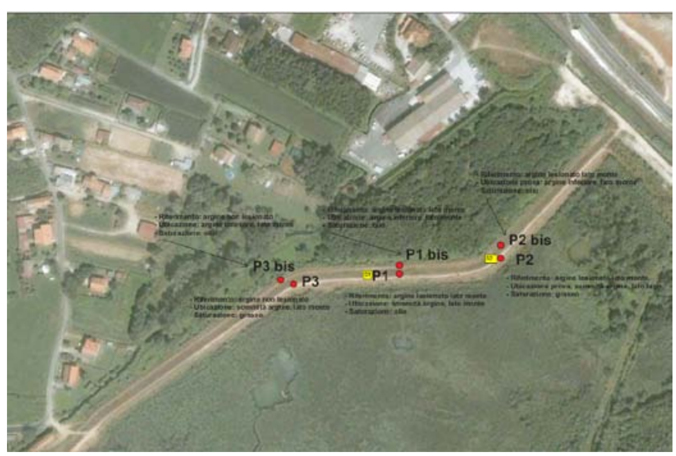

Fig. 1. Location of site investigations along the existing bank. (Red dots: P1, P2 & P3 CPTU carried out from the top of the bank; P1bis, P2bis & P3bis are carried out from the bottom of the bank. Only the results from P1bis and P2bis are available for students. Yellow squares indicate locations of boreholes S1 & S2). Scripts in Italian and arrows close to P1 – P1bis &P2 P2bis show the existence of failure surfaces. The scripts close to tests P3 & P3bis show that no sign of failure has been observed in that area.

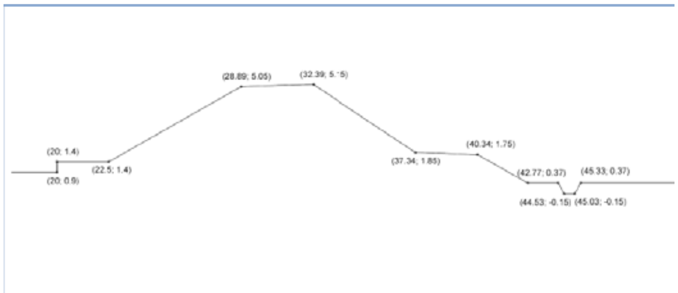

Fig. 2. Cross section of the existing bank.

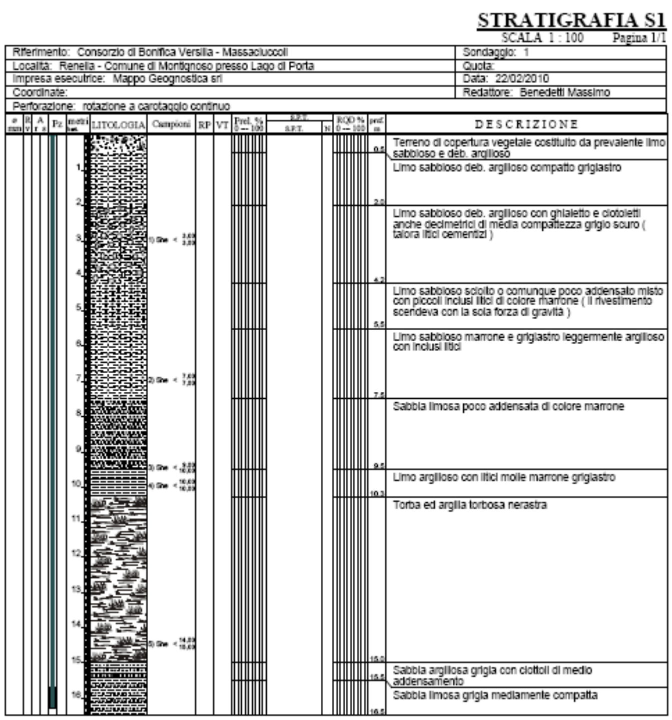

Fig. 3. Stratigraphic log of Borehole S1. Peat and clay are indicated below 10.3 m depth but peat material is also detected after 9.5 m. Medium stiff sand is below 15.0 m depth. Identification of peat is more clear from CPTU reported below

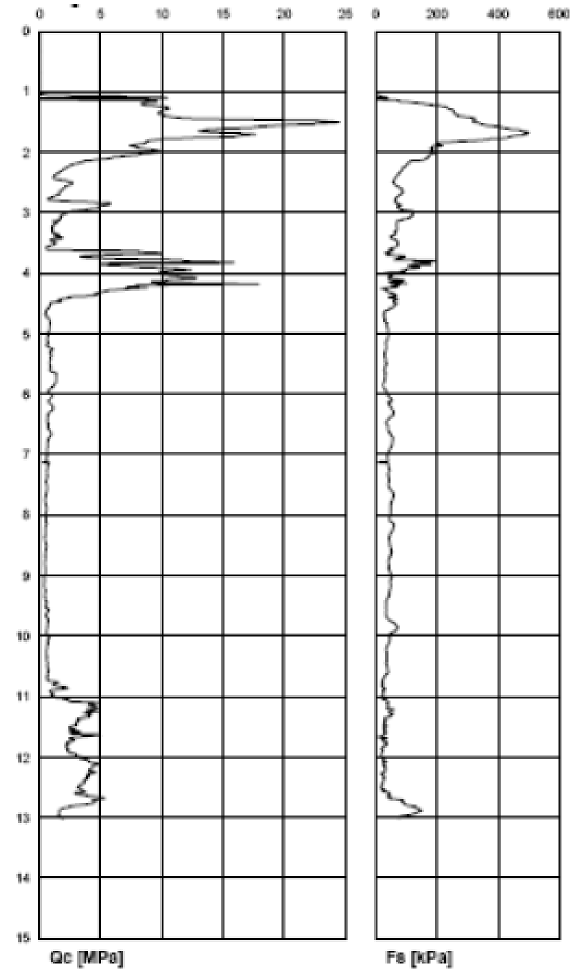

Fig. 4.a. Results from CPTU P1bis: qc and Fs.

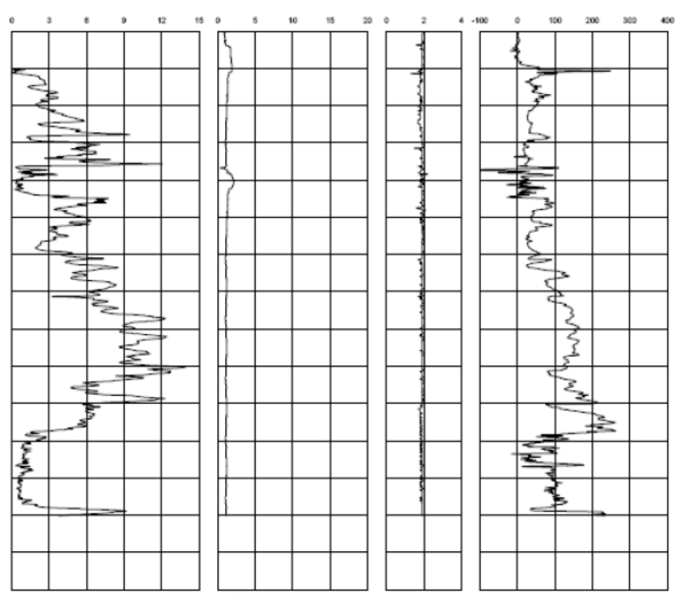

Fig. 4.b. Results from CPTU P1bis: Rf and u.

						Casagrande		
Tensioni	ΔH	H	$H_{[illegible]}$	e	M	Cv	k	$C_{[illegible]}$
[kPa]	[mm]	[mm]	[mm]	[-]	[MPa]	[cm²/s]	[cm/s]	[-]
0.0	0.329	20.00		3.973				
12.5	0.329	19.67	19.84	3.891				
25.0	0.810	19.19	19.43	3.772	0			
50.0	1.126	18.87	19.03	3.693	1			
100.0	2.071	17.93	18.40	3.458	1	1.43E-05	1.48E-09	2.84E-02
200.0	3.571	16.43	17.18	3.085	1	2.31E-04	2.07E-08	5.14E-04
400.0	7.321	12.68	14.55	2.153	1	1.38E-04	1.99E-08	1.60E-02
800.0	9.026	10.97	11.83	1.729	3	6.25E-05	2.38E-09	1.45E-02
1600.0	10.490	9.51	10.24	1.365	5	4.06E-05	7.66E-10	1.41E-02
3200.0	11.906	8.09	8.80	1.013	9	3.07E-05	3.29E-10	1.26E-02
800.0	11.542	8.46	8.28	1.103				
200.0	10.920	9.08	8.77	1.258				
50.0	10.359	9.64	9.36	1.397				
12.5	10.181	9.82	9.73	1.442				

Fig. 5.a. Example of a good quality odometer test: measurements.

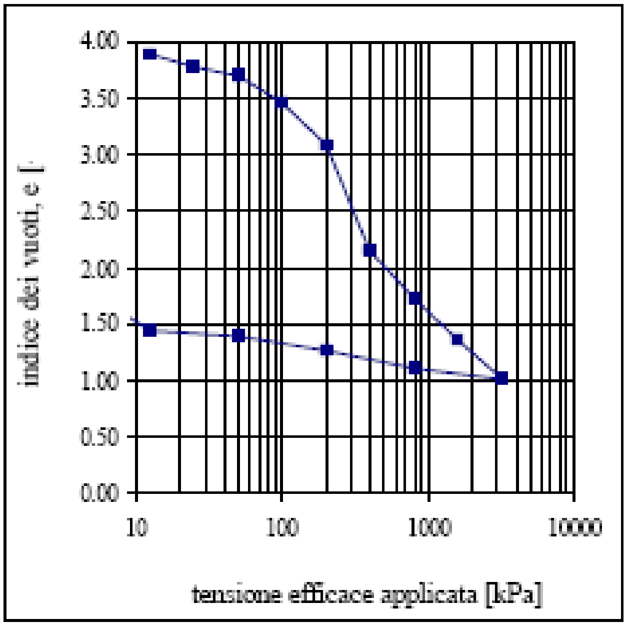

Fig. 5.b. Example of a good quality odometer test: plotted results.

Fig. 5.c. Example of a good quality odometer test: picture of tested sample (borehole S1, sample C3).

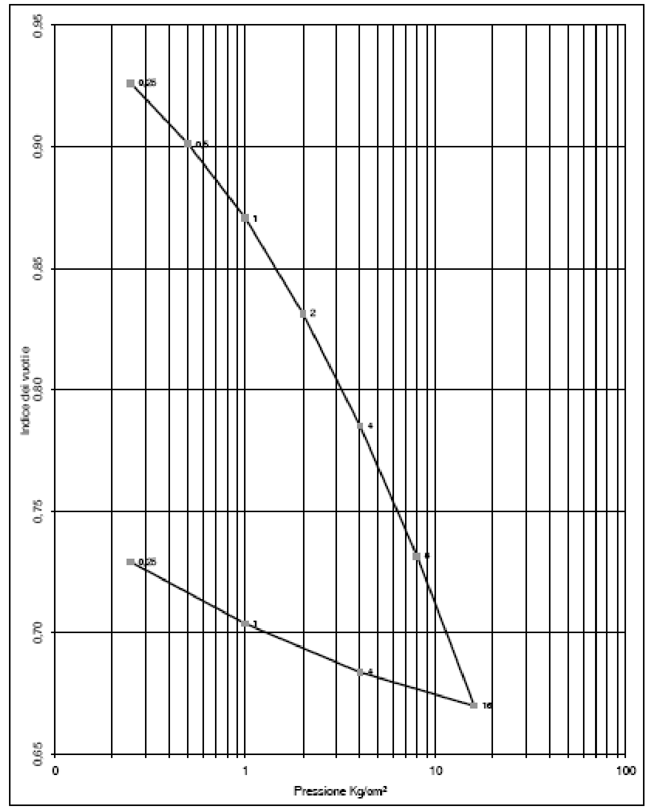

Fig. 6.a. Example of an odometer test using a sample of low quality: plotted results.

Fig. 6.b. Example of an odometer test using a sample of low quality: picture of tested sample (borehole S1, sample C4).

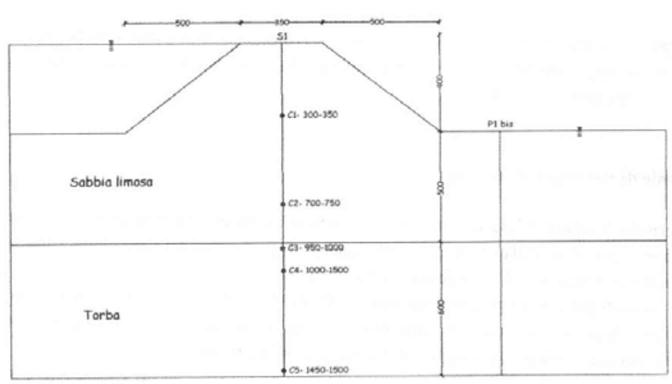

Fig. 7. Simplified geological/geotechnical model. The characteristic values of the strength parameters have been reported. Design values have been used for the analyses. (RR =Cr/(1+e_0)= Recompression Ratio; CR = Cc/(1+e_0)= Compression Ratio, i.e. the slopes of the curve ε_v-log(σ'_v) during recompression till the preconsolidation pressure and beyond the preconsolidation pressure).

ADVANTAGES AND DISADAVANTAGES OF THE PROPOSED APPROACH

The class has been attended by 40 students in the period October 2010 – January 2011. As of April 2011, most of the students have already successfully passed the examination. Examination is split into two parts: 1) written examination which consists of solving a problem related to one or more topics of the subject, 2) oral examination which consists of answering questions on various topics of the subject and explaining the results obtained from the case study. Upon passing the examination, the students have completed successfully 6 credits. The quality of the work done for the case study only affects the final mark. In the following subsections, advantages and disadvantages of the proposed approach are highlighted. In order to evaluate the potential positive aspects of the proposed methodology, it could be useful to define some quantitative indicators. Unfortunately, until now an objective assessment of the advantages of such an approach is not available. Therefore, the paper qualitatively illustrates potential advantages and drawbacks of the proposed methodology.

Advantages

On the basis of the personal experience of the author, it is possible to point out the following positive aspects obtainable by the use of case histories:

- to stimulate passion and interest of students in the subject matter;
- to facilitate the understanding of student independently of her/his own background;
- to facilitate the learning process of general concepts;
- to allow brilliant students to develop a deeper insight without penalising less brilliant students;
- to teach problem solving.

Passion & interest. Is a matter of fact that young people are attracted by the possibility of participating in projects related to the region where they live. The idea is to do something useful for their community and to act as a “practicing engineer”. As an example, the design of a road in Tuscany seems to young students more attractive than studying the behavior of a “light” road embankment. The point is that a particular application (local project or a relevant project like the stabilization of the Leaning Tower or the design of the one-span suspension bridge over the Messina strait) has more attractiveness than a research study whose results could be applied everywhere. Likewise, the development of a new piezocone is less attractive than performing CPTU nearby Pisa to solve a given practical problem. The use of a local case history, meets the above idea and is capable of stimulating passion and interest.

Understanding. Usually, a given subject is taught following a systematic approach. According to this approach, the subject is split into homogeneous topics. Each topic is completely developed by means of lectures and sometimes by means of practical training (problems). Lectures are mainly used to derive from principles_of physics or from past experiences some basic solutions, but the practical use of such solutions may remain obscure. On the contrary, the study of a case history gives the students a very different perspective. For the considered case history, students have to think about the engineering problem (the stability of the bank) evaluating possible mechanical or hydraulic failures or excessive settlements (including the time required to complete the settlement of the underlying layer). The comprehension of the aims of the available solutions certainly enhances the understanding of the solution methods (i.e. their capabilities and limitations).

Learning. Usually students begin studying a given subject after the end of the class. Often, in Italy the subject is studied months or semesters after the end of the class. This delay strongly reduces the learning capability. On the contrary, the need of using what has been presented during the lectures in the classroom to solve the given case history greatly enhances the learning capability. In addition, it is worthwhile to emphasize that the practical problems that are typically proposed and solved in the classroom adopt oversimplified soil profiles already defined by the Teaching assistants. Approaching the given case study, students learn that:

- geological/geotechnical model has to be assessed by means of testing;
- testing is redundant
- not necessarily all the test results will be used. Some results may not be used for various reasons as previously discussed.

Obviously, student work has to be supervised step by step, which requires a number of Teaching assistants (two for the case under discussion, as already mentioned).

Opportunities. Students can use the various available tools and reach the following conclusions:

- the mechanical stability of the bank is NOT a real problem. A safety factor of about one is obtained from undrained block analysis, when considering a potential failure along the contact of the soft organic layer with the underlying stiff sand. The design parameters have been used for this type of analysis. All other analyses led to very high values of the safety factors;
- the hydraulic stability (seepage) of the bank is NOT a real problem;
- following construction, the settlement of the bank, will be about 80 – 100 cm (odometer settlement at

the centre of the bank) and it will take decades to be completed.

Usually all students should be capable of obtaining the above listed answers from their analyses. Anyway, brilliant students could ask themselves the following questions:

- Is it possible to have a differential settlement between centre and edge of the bank?
- How could I compute the differential settlement?
- Is it possible that a high differential settlement can lead the bank to an ultimate limit state?
- Why do we study separately seepage, mechanical stability and settlement?

As for the proposed countermeasures, most of students could suggest the use of radial consolidation by means of vertical drains to reduce the consolidation time, anticipating most of the expected settlements. Brilliant students could think about the effects of these large consolidation settlements on the bank resting above the soft organic soil and the re-profiling works that become necessary after the settlements have occurred.

Therefore, when addressing a case history, brilliant students have the opportunity to reach a deeper comprehension of the problem and of the available solutions. This does not penalize the less brilliant student.

Obviously, we don't expect to have always so brilliant students. For instance, in our first experience, none of the students went beyond the results of a basic analysis and solution.

Problem solving. The only way to teach problem solving is through case histories. Anyway this requires more time for the teaching staff (totally 9 hours per week instead of the 5 hours per week of lectures) and for students. In addition, this teaching approach requires to have a number of case histories in order to change year by year.

Disadvantages

The main risk of the above outlined approach is that students end up with a mere mechanical application of rules without a clear understanding of what they are doing. There is no way to avoid this risk. One possibility, according to the Peck's approach is to ask students to summarize the whole case in one page (just one page). Based on the personal experience of the Author, the examined students have shown, discussing the results of the case history, a very good understanding of their activity.

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