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Students as Forensic Engineers: An Innovative Approach to Teaching Soil Mechanics

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STUDENTS AS FORENSIC ENGINEERS: AN INNOVATIVE APPROACH TO TEACHING SOIL MECHANICS

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ABSTRACT

Civil engineers are everyday faced with multidisciplinary problems. Their tasks are not only related to technical aspects, but also involve ethical and environmental issues, economic considerations and, nowadays, international collaborations. This broad spectrum of aspects requires a strong technical knowledge, as well as many interpersonal skills and an interest in societal related issues. When traditional courses are simply adapted to the development of technical competences, introducing students to non-technical (although civil engineering-related) aspects remains a challenge. To remediate to this difficulty, an innovative approach was implemented in the undergraduate course of Soil Mechanics at Polytechnique Montreal. The originality of our approach relies on the study of failure case studies from a forensic point of view and on the challenge of students with real world multidisciplinary applications. Students are thus entirely involved in the case study and act as investigators recruited to find the cause of a failure and its impact on social and environmental issues. This methodology prevents student passivity and the role of the professor is only to guide students towards a holistic understanding of the events, rather than suggesting solutions for them. The paper will present the overall course design and outline, from the selection of the failure case study to its implementation into the curriculum.

INTRODUCTION

Civil engineering is not limited to the construction or the design of buildings, but is a multidisciplinary domain involving technical aspects, project management and human considerations. As a consequence, civil engineer students have not only to receive a strong technical formation, but also to be sensitized to non-technical aspects of engineering.

To address all multidisciplinary aspects, Polytechnique Montreal uses a curriculum composed of a strong technical base ranging from geotechnical to structural engineering and some parallel courses, such as ethics or economy. Nevertheless, a link has to be done between non-engineering and engineering topics to introduce students to project management, which represents a challenge composed of a variety of problems. To this end, team projects have been introduced in curriculums at Polytechnique Montreal to place the students in a situation of management, where they have to refer to different domains to find technical and economical solutions to a pre-defined problem. This situation could be seen as a top-down relation, from the management to the technic or from the need to the solution. On the reverse angle, we tried to input a new approach in the course of soil mechanics by putting the students in a technical situation and asking them to go backward to the constraints of management, economy or human relations.

This new approach relies on the use of case studies as a support of motivation and concrete student training. Indeed, Raju and Sanker (1999) demonstrated the importance of using case studies in engineering education to expose students to real-world issues and case studies have also been linked to the increase of student motivation and interest in a subject (Mustoe and Croft, 1999).

The use of case studies is opposed to traditional classrooms where artificial problems are created to apply a new notion such as a structural or a geotechnical theory. As the use of artificial problems reinforces the viewpoint that projects are a collection of individual problems such as schedules, structural concepts, or environmental hazards (Chinowsky and al., 1997), we decided to base our approach on a case study presented within lectures all along the semester. The use of a recurrent case study during the semester illustrates the complexity of engineering problems. It is opposed to single-focus case studies that fail to highlight the numerous interdisciplinary forces and can therefore give an inadequate understanding of the civil engineering profession to the students (Chinowsky and al., 1997).

The originality of this article relies on the preparation of the case study to match the course of soil mechanics during the whole semester. Some aspects of the case study are presenting to illustrate a typical intervention in a lecture and the way to link technical considerations to non-technical constraints.

COURSE OF SOIL MECHANICS

The curriculum of civil engineer students is composed of 4 years and the course of soil mechanics appears in the third one, just before specialty orientations such as building and civil engineering structures, environment, transportation, geotechnical engineering and applied hydraulics.

Course in the curriculum

This course is mandatory for students in the civil engineer curriculum and is preceded by the material's resistance course, which is a prerequisite. Indeed, students need to have some good notions of stress, deformation, stress-deformation relation, tensile, compressive and shear strength, principal stresses, and Mohr's circles to succeed in this course.

Without being a formal prerequisite, the course of general geology represents an asset for the comprehension of the formation of soils and the mineralogy of clays.

Although it comes quite lately in the curriculum, the course of soil mechanics constitutes an introduction to geotechnical engineering and the attraction of students to this field of engineering represents a challenge. Indeed, most of them have been interested by the first courses in the curriculum and have already chosen their orientation. As a consequence, many students chose deliberately another specialty, even though they find the initiation to geotechnical engineering very useful. Even if the position of this course is not appropriate to catch an early on attention of students, it would be difficult to modify the curriculum. Indeed, students have to know how to design a building and how to calculate the load lowering in order to design a foundation able to respond to these constraints.

The second challenge of this course is to attract students for graduate studies in geotechnical engineering.

Course structure

The course is composed of twelve three hour long lectures, 7 laboratories and 12 recitation classes. The Table 1 presents the themes studied along the semester.

Table 1: Planning of the soil mechanics lectures

1	**Description and classification of soils (I)**: physical indexes, phase relations, grain size curve.
2	**Description and classification of soils (II)**: Atterberg's limits, classification.
3	**Description and classification of soils (III)**: clayey minerals, structure of soils **Compaction**: theory, material and method, specifications and control.
4	**Stresses in soils**: total and effective stresses, vertical and horizontal stresses.
5	**Water in soils (I)**: capillarity, shrinking, swelling, frozen soils.
6	**Water in soils (II)**: permeability, hydraulic head, Darcy's law, one-dimensional flow, quicksand.
7	**Water in soils (III)**: flow nets, filters.
8	**Consolidation and settlement**.
9	**Rate of consolidation**.
10	**Mohr's circles and theory of rupture** : - Transformation of constraints, - Mohr-Coulomb criteria, - Direct shear test, - Triaxial test principle (CD, CU, UU).
11	**Shear strength of non-cohesive and cohesive soils**: - Behavior of sands in CD and CU triaxial tests, - total and effective stresses analyses, - behavior of clays in CD, CU and UU triaxial tests.
12	**Synthesis**: key elements

Learning objectives

This course represents an initiation to geotechnical engineering. As such, it does not intend to form students able to design a retaining wall, an earth dam or a deep foundation, but aims to give them a strong knowledge related to mechanical and hydraulic behaviors of soils. This common minimum represents a prerequisite for their future courses, such as foundations, excavations, dikes and earth dams, and road infrastructures. At the end of this course, the students are able to:

- classify the soils based on their composition and their behavior,
- analyse the phase relations of a soil element,
- select laboratory tests to respond to a given geotechnical problem,

- analyse the results of basics laboratory tests
- describe the theory of compaction of soils
- describe the effects of water on the behavior of different soils,
- evaluate the groundwater flows by analytical methods,
- draw a flow net under a dam or a foundation,
- calculate the total and effective stresses in a soil,
- analyse the compression of a soil layer,
- calculate the degree of consolidation of a clay,
- solve basics geotechnical problems, such as one dimensional settlement.

CASE STUDY PRINCIPLE

To reinforce the attraction of this course, a new planning relying on a case study has been introduced since August 2012. The idea of this new approach is to present a real problem of engineering to initiate the students to non-technical constraints. This approach intends to sensitive the students to the job that they will exercise all along their career and, at a smaller term, to catch their attention for the rest of the curriculum. Ethical considerations such as safety and security also constitute an important aspect introduced in the course.

As previously mentioned, the case study is used throughout the semester and we refer to it each week. This case study is used as a support for the discovery of new concepts by the students and aims to apply the theory immediately. References to the case are done at the end of lectures, during a 10 to 15 min presentation. Among the 12 lectures, 10 contain references to the case study as presented in Table 1. A reference to the case study represents the illustration of each main chapter in the planning.

Studying a case presents some benefits as an interactive learning strategy, shifting the emphasis from teacher-centered to more student-centered activities (Grant, 1997), and active learning activities such as small group reflection before sharing with the class are also used to reinforce this interaction.

The scheme of each reference to the case study is as follows:

- Brief links to the lecture to highlight the main points of the course,
- Presentation of an element related to the case study: particular design, choice of materials, geology, hydraulic…
- Problematic or question related to this element: *why a particular design has been retained? What is the impact of the geology on the project? Could we have chosen other materials for the construction of the project?*
- Reflection in small groups (3 to 4 people)
- Answers and synthesis with whole classroom.

Case study preparation

Preparation of the case study and lectures had to be done simultaneously to insure a complementary cohesion between the concepts learned in class and a portion of the case study.

During the summer of 2012, this course received funds from the Center for teaching and learning to improve its course notes. This fund was dedicated to the recruitment of two students who had passed brilliantly the course and who worked to prepare the notes for the case study. The implication of previous students, able to take a step back in relation to the course was very important.

Their summer internship was divided into three parts:

- Bibliographic study related to the case (reports from experts, papers…),
- Research related to case studies in teaching,
- Preparation of a PowerPoint support for each presentation of the case.

Case study selection

To select the case study, we had to deal with several constraints. The case study has to be important enough to cover all the matter learned in classes. On the contrary, the notions presented in the case must stay at a basic level as the course is just an introduction to geotechnical engineering. Finally, the case study has to cover non-technical aspects, such as economics, human relations…

To sensitize students to the responsibility of engineers, we decided to choose a case of failure and our attention had been pointed to the Teton Dam failure, in 1976. This choice is justified by:

- the multitude of documentation related to this dam: reports from experts after the failure, papers, pictures, videos…
- the relative simplicity of the design for a young geotechnical engineer: earth dam involving soil compaction, no deep foundation, except a cut-off wall…
- the implication of economy via the choices done during the construction and the damages resulting from the failure.

TETON DAM CASE STUDY

Teton dam is unfortunately known as the highest embankment dam that had ever failed in the history of earth dams.

History

As illustrated on Fig. 1, Teton Dam was located in the south-east of Idaho, approximately 64 km northeast of Idaho Falls.

This dam was designed for multipurpose, such as flood control, power generation, recreation, fish and wildlife mitigation measures, and irrigation of 110,000 acres in the Fremont-Madison Irrigation District (Schuster and Embree, 1980). This earth fill dam had a maximum height of 122 m, was 940 m long and was supporting a reservoir whose capacity was 333 Mm^3. It was constructed under the supervision of the US Bureau of Reclamation and the construction was attributed to the consortium Morrison-Knudsen-Kiewit. Fieldwork started in June 1972 and the first filling up started in October 3rd, 1975. Unfortunately, the dam failed during this first filling up on June 5, 1976 (Jansen, 1980).

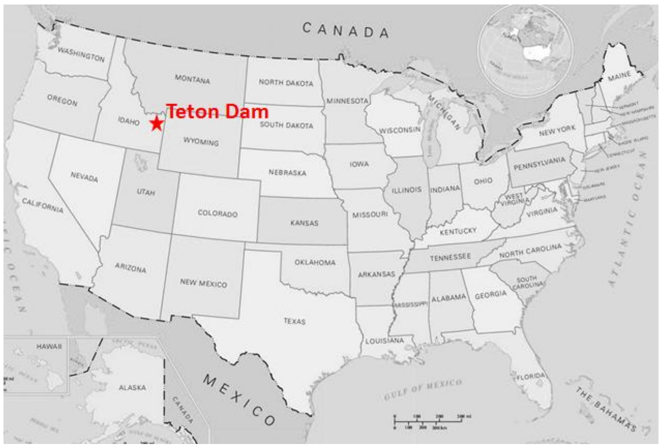

Fig. 1 : Location of the Teton Dam

Approximately 308 Mm^3 of water and 3 Mm^3 of materials were spread in the river in about 6 hours (Lloyd and Watt, 1981). The downstream destruction zone was very important and reached the upper end of American Falls Reservoir, located 95 miles from the dam. The maximum flowrate was estimated at 28 300 m^3/sec and was the source of deaths, inundation and destruction.

This failure resulted in the death of 14 people and created an unparalleled event in the history of Reclamation. Even though legal experts stated that the Federal Government was not liable for the flood damage, the Administration pointed out that the United States had a moral obligation, and a special mention was adopted to pay for damages. Thus, a compensation slightly less than 400 million US$ was paid to claimants and contractors who repaired the flood-damaged infrastructures.

After the failure, two independent groups were constituted to investigate the failure: the Independent Panel (IP) and the Interior Review Group (IRG). The IP was composed of nine internationally recognized engineers, while the IRG was composed of representatives from five Federal agencies concerned with dam construction. Three reports were produced by these groups: IP, 1976; IRG, 1977 and IRG, 1980.

<u>Local hydrogeology</u>

Teton Dam was located in the Teton River canyon, whose geologic area is bounded by the Rocky Mountain and the Snake River Plain. The major geologic activities in the area are the uplift of the Teton and Snake River and the associated volcanic activity from Island Park and Yellowstone area (Randle and al., 2000). During the late Pliocene and early Pleistocene age, a flow of rhyolite coming from Yellowstone Caldera was deposited over a pre-existing irregular landscape and formed the Huckleberry Ridge tuff , a 70 to 200-meters-thick formation (Pierce and Morgan, 1992).

The Teton River has cut a volcanic plateau, known as the Rexburg Bench, resulting in a steep-walled canyon. The canyon walls were composed of welded ash-flow tuff of rhyolite. The north wall was very steep or vertical, and the south wall was less steep and composed of a poorly sorted mixture of talus, colluvium, and loess coming from the plateau (Randle and al., 2000). Some alluvium had been deposited in the river channel to a depth of about 30 m (Sasiharan, 2003). A cross-section of the canyon is provided in Fig. 2.

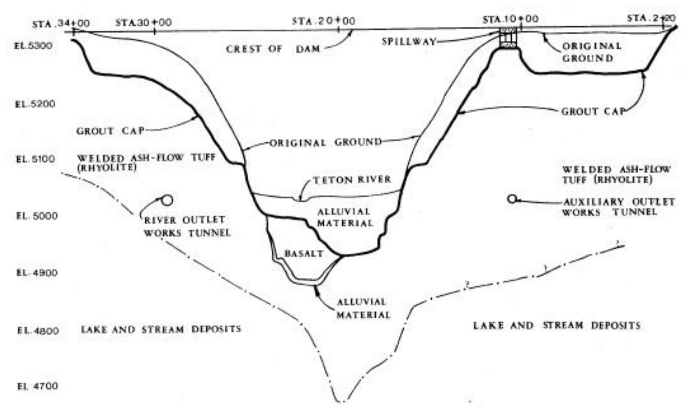

Fig. 2 : Cross section of the Teton River

As for all construction projects, extensive site exploration was performed prior to construction. Percolation tests and pumping tests revealed that the joints in the rhyolite-tuff were able to transmit up to 380 l/min. These results demonstrated that the extensive joint system was extremely permeable and needed to be sealed to reduce the leakage to acceptable quantities. Nevertheless, some pilot tests demonstrated that it would have needed huge quantities of grout and that it would be more economical to remove the top 23 m of rock and incorporate a deep key trench to prevent seepage (Sasiharan, 2003).

It is finally important to mention that the high lands are covered with loess in the area of the Teton River. The thickness of this aeolian silt deposit can reach 9 m, which represents a great quantity of material leading engineers to use it the core of the dam.

Reservoir filling and failure

Reservoir filling began in November 1975 and the water level started to rise rapidly during the spring of 1976. According to the design of the reservoir, the filling rate was expected to be less than 30 cm per day, but an abnormal spring run-off and some delays for the completion of the works resulted in a higher filling rate reaching 120 cm per day during May 1976. By June 5^{th}, 1976, the water level was only one meter below the spillway crest and 9 m below the embankment crest.

Abnormal observations were done two days before the failure, when some small springs were observed at the riverbed level about 450 m downstream from the embankment. On June 4^{th}, some additional springs had developed about 120 m from the downstream toe, but an immediate inspection of the upstream and downstream slopes of the embankment showed no unusual condition. After these first observations, the failure took place as follow:

- at 7h00 a.m. on June 5^{th}, some water was flowing from the downstream face of the embankment, about 40 m below the crest of the dam (see Fig. 3). The flow was about 56 l/s;
- at the same time, a flow of about 700 l/s emerged from the talus, near the toe of the embankment;
- during the next three hours, the flow from the downstream face increased progressively up to 425 l/s at about 10h30 a.m.;
- after this time, the seepage increased rapidly accompanied by progressive upward erosion (see Fig. 4) and the complete failure occurred at 11h55 a.m. (see Fig. 5).

Fig. 3 : initiation of the failure

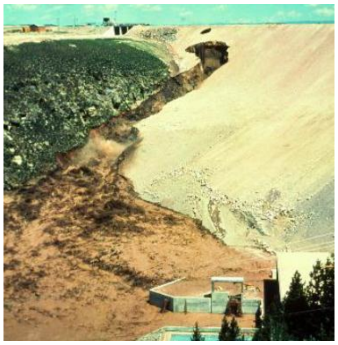

Fig. 4 : progressive upward erosion

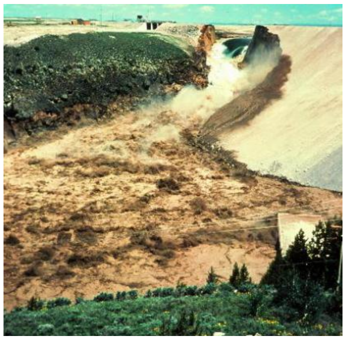

Fig. 5 : Failure of the Teton Dam
Photography credit : Arthur G. Sylvestre

Investigations by the independent panel (IP 1976)

According to the Independent Panel, two mechanisms were most likely to have led to the failure. The first hypothesis was related to seepage under the grout cap in unsealed joints of the rock. This phenomenon would have led to erosion along the base of the trench resulting in a piping failure through the key trench fill. Some investigation tests revealed the presence of non-sealed joints beneath the grout cap, reinforcing this hypothesis. Nevertheless, no leaks were observed prior the failure as it should had occurred if the phenomenon had contributed to the failure.

The second hypothesis was related to hydraulic fracturing or differential settlement resulting in a piping failure. Fracturing tests and finite element analysis concluded that the stress distribution could have led to hydraulic fracturing in the core due to high water pressure upstream. Nevertheless, their experimentation to generate hydraulic fractures in the field did not succeed.

The IP concluded that although they described two main mechanisms for the initiation of failure, it was impossible to provide a final answer to the specific cause of failure of Teton dam.

Investigations of the interior review group (IRG 1977)

The first conclusions of IRG's report stated that the Teton Dam was constructed as specified and failed as a result of inadequate protection of the impervious core from internal erosion. The cracking of the core material was pointed out as the most probable mode of failure, but interface erosion at the contact between the core and the rock was mention as another probable mode.

However, the IRG recommended additional investigations which consisted in testing the grouting conditions, excavating the left part of the dam and performing finite element analysis to support the study with relevant parameters. Some of these further investigations will be present later in this article, as a part of the case study presented to the students.

USE OF THE TETON DAM CASE STUDY IN THE COURSE

The detail of the case study presentations is provided in Table 2. As explained earlier, each presentation has to be linked to the lecture and the themes are imposed by the course outline. Two case study presentations are detailed in the next paragraph as an illustration of the teaching approach.

Table 2: Planning of the case study presentations

Theme of the lecture	**Case study**
Description and classification of soils (I)	• Presentation of the Teton Dam: localisation, geology, failure…
Description and classification of soils (II).	• Classification of the dam's materials: core, faces, • Problem of Loess chosen for the core, • Atterberg's limits for the core
Description and classification of soils (III) Compaction	• Optimum Proctor curves used for the design of the dam. • Method of compaction of the core.
Stresses in soils	• Influence of water on the mechanical behavior of Loess.
Water in soils (I)	• Stresses in the core.
Water in soils (II)	• Treatment of the dam's foundation (waterproofing)
Water in soils (III)	• Flow net in a section of the dam. Drainage.
Consolidation and settlement.	• Effect of first filling up on the deformation of the dam.
Rate of consolidation.	
Mohr's circles and theory of rupture.	• Dam's behavior in case of quick drawdown.
Shear strength of non-cohesive and cohesive soils.	• Slope stability (dam and canyon located upstream).
Synthesis: key elements	• Case synthesis

Classification of soils

The presentation of the different materials involved in the dam is a very good application of the Unified Soil Classification System. Indeed, the dam contains five different zones with five types of soils, from clayey silts to rocks as illustrated on the simplified cross section provided on Fig. 6.

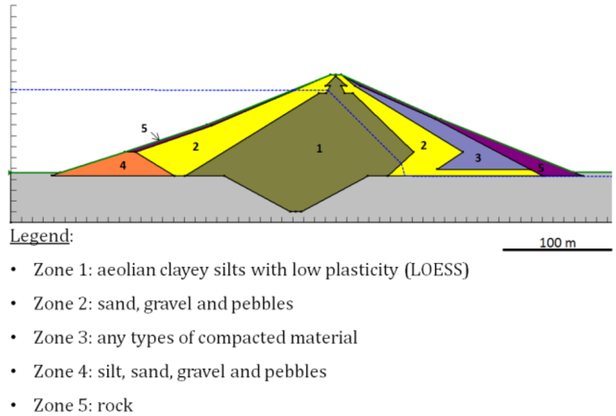

Fig. 6 : Schematic cross-section of Teton Dam

With respect to the multitude of post-failure investigations, a huge data bank related to the characterization of the soils was available. As a consequence, we could easily give some classification indexes to the students and ask them to classify the soils in each zone. This first application was a good opportunity to sensitize the student to the function of each zone, such as:

- fine material in the core to ensure its function of impermeability,
- well graded material disposed immediately against the core to ensure its function of filtration and to prevent any erosion,
- coarse material at the extremity to prevent the action of water and precipitation.

The focus of this presentation was pointed to the material that played an important role during the failure: the core of the dam. Given its grain size curve whose percentage passing under mesh 200 was approximately 88%, the students easily determined that it was a silt and clay. Given the results of the Casagrande liquid limit test device (27%) and the plasticity limit equal to 23%, the students deduced that the plasticity index was about 4% and that the soil was classified as a CL-ML, that is to say some clays and silts with low plasticity. This finding closed the first step of direct application of the course and, given this result of classification, the first question was: *according to the course that has just been presented, can you explain what would be the influence of water on the mechanical behavior of this soil?* After a long blank, some questions or remarks came from the class:

- we just have two results related to Casagrande's device and plasticity manipulations. How can we quantify the influence of water on this soil?
- no indications related to the behavior of the soil with respect to water are given …
- don't we need any additional information related to mechanical tests?

These remarks pointed out that the students had listen to the course, but did not assimilate the notions of plasticity and liquidity limits. When reminding that the behavior of a soil is “solid” when the water constant is under the plasticity limit and “semi-liquid” while it remains above the liquidity limit, the students did the link between the mechanical behavior of a soil and its water content. The expected response came immediately after this reminding and a student explained to the others that a change of only 4% in the water content can change the behavior of the soil, from solid to liquid. Finally, they realized that the 4% only represents 40L of water for 1000 kg of dry soil! This illustrate clearly that the definition of plastic and liquid limit did not means anything without an actual example. The manipulation of numbers instead of symbols helped to assimilate the physical signification of the definitions introduced in the course. This application done, we continued the case study by presenting in detail the material chosen for the core and finally address non-technical constraints.

This core has been realized with loess, which are aeolian materials transported in periglacial conditions and deposited in cold steppe, mainly around the 50° N parallel to the northern hemisphere, even if there is also some deposits in South America (Muñoz-Castelblanco, 2011). The typical process of formation of loess is as follow:

1. Fine particles produced by glacial abrasion are washed, transported by proglacial flows and deposited near existing moraine.
2. Particles of sand, silt and clay are subject to cycles of freezing and thawing. They are eroded and transported by the continuous action of cold and dry winds. These winds are created by existing high pressure over the polar ice caps.
3. Sand particles, larger and heavier, are deposited first in the form of dunes and superficial layers.
4. Particles of silt and clay are transported to areas of low pressure in high atmosphere. Finally, these fine particles are deposited due to several factors: climate change, decrease of the wind speed, presence of obstacles, captured by the vegetation or snow cover (Antoine, 2002).

Loess are mainly composed of silt-sized particles of about 5 to 80 microns and an important fraction of clay. They generally have the following characteristics (Smalley, 1971; Jamagne and al., 1981; Lautridou, 1985; Pécsi, 1990):

- homogeneous structure and porous,
- absence of stratification,
- abundance of particles of about 30 mm silt, clay (15-18%), and sand (<2%),
- presence of carbonates,
- predominance of minerals such as quartz grains (≌ 70%), iron (1.5 - 2%) and organic carbon (0.2%).

In the case of the Teton dam, the loess have been derived from the Rocky Mountains and carried into the Idaho by the Snake River. The volume of 3 965 466 m^3 necessary for the realization of the core has been taken in the area of the dam.

As regards their mechanical behavior, the loess have a very low plasticity and are fragile and dilatant, meaning that they are easily erodible (formation of channels) and that they can loss their waterproofing function.

This presentation done, the forensic question to the students was: *with respect to their poor mechanical characteristics, why did the engineers choose the loess for the realization of the core?* Here started a discussion about the incompetence of engineers, the irresponsibility of people involved in this project or the lack of knowledge at that time. Finally, a student guessed that this soil was the cheapest for the core. After investigation, they realized that the transportation of the soil represents a major element of the cost of an earth dam and that the volume of 3 965 466 m^3 represent approximately 2 203 036 T of soil and, if we consider a load of 15T per truck, 146 869 trucks, that should be multiplied by the number of kilometers done by each truck… a good reason to explain the choice of local material for the realization of the core and to continue the discussion on the topic of ethics. Students finally realized that non-technical aspects can represent some severe constraints on a project, but that no concession should be done with the security of people.

Compaction

The second example deals with the compaction of the different zones. During the post-failure investigations, the embankment fill overlying the left abutment key trench was excavated for inspection. The Fig. 7 presents the dam nowadays, where we can see the zone of failure on the left of the picture and the zone of investigation on the right. This excavation was performed during the summer 1977 and did not revealed any findings of major significance, except a thin zone of soil with a very high water content encountered at a depth of approximately 66 m from the top of the dam. The discovery of this extensive wet seam on the left side of the embankment immediately led to the speculation that a similar seam could have generated the failure on the right of the embankment. Following the presentation of these investigations, the opinion of the students on the wet seam theory has been asked. Here started a succession of suppositions guided by new results of investigation given step by step to the students.

Fig. 7 : Teton Dam nowadays
Photography credit: U.S. Bureau of Reclamation

Firstly, the IRG report (1980) revealed that the location of the wet seam was essentially parallel and just above the winter shut-down surface (1974-1975). As a consequence, the forensic reflection of the students pointed out that this area was realized during the spring of 1975 and that the effect of frost action on the soil to explain the presence of the wet seam has to be discarded: a conclusion similar to the IRG report and a good opportunity to make a digression about the damages that could be performed by the frost action.

The second element given to the students concerned the precipitations encountered during this period of construction. Indeed, there were two extended period of shut-down due to wet weather from April 29th to May 29th, 1975, and snow or rain occurred during the construction on May 5th, 6th, 19th, and 21st, 1975. This new information was immediately followed by interjection from several students referring to the course that they were just listening to. These students leaded the discussion and explained that this wet weather could have impact the compaction ration and the quality of the core: a direct application of the course….

Moreover, some indications regarding the control during the construction were given to the students. In particular, the daily reports revealed that the earthwork inspection staff did not reach its full capacity until May 12th, 1975, and that the frequency of the control tests was lower than required in May, 1975. Once again, this element permitted a discussion about the responsibility of the engineers and the need of controls, which could have revealed the bad compaction of the wet seam zone. The hypothesis about the reason why the inspection staff did not reached its full capacity also lead to a discussion about human constraints in a project.

Finally, the course was closed with expert's conclusion about the eventual presence of a wet seam in the zone of failure. These experts concluded that it seems unlikely that a similar wet seam could have existed on the other side of the dam for the following reasons:

- the elevation of the winter shut-down surface (1974-1975) was higher in the zone of failure than in the zone investigated,
- the wet seam observed in the investigated zone was placed during the period from May 1st to May 29th, 1975, while the filling in the failure zone restarted only at May 29th. No anomaly was observed in the investigated zone placed after that date, and we can guess the same for the failure zone.
- No evidence of any wet seam on the exposed face of the embankment after the failure had been encountered.

CONCLUSION

The introduction of case studies in the curriculum of civil engineer students permits to illustrate non-technical aspects of a project. Study of failures such as Teton Dam is particularly interesting from an educational point of view because it unfortunately illustrates the implication of engineering activities. As a consequence, a failure reinforces the potential impact of economical, human or environmental constraints on a project and attends to inculcate responsibilities and ethics to these future engineers.

Starting from a technical aspect presenting a default of conception, the students have to understand the reasons leading to an inappropriate choice of materials, design, methodology or control of the works. This approach stimulates self-reflection of students and reinforces their conception of responsibilities in their future profession.

This methodology is presently testing in the course of soil mechanics at Polytechnique Montreal and future works related to this new approach will consist in an evaluation of the course at the end of the present fall 2012 session.

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