# EDUCATION IN MINE WASTE ENGINEERING: THE EXPERIENCE OF "SIGEO" MASTER

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## Introduction

The catastrophic failure of the tailings dams serving the Prestavel fluorite mine in the Stava Valley (Province of Trento, Italy) occurred on 19th July 1985. It caused the loss of 268 lives and vast material and environmental destruction (Fig. 1). On account of its magnitude and number of victims, the catastrophe of the Stava Valley is one of the worst disasters caused by the failure of tailings dams worldwide [1].

Fig. 1 – Stava Valley, Italy: the devastating effect of the flowslide (July 1985)

The Italian Court of Appeals ruled that the collapse of these dams was foreseeable and could have been avoided [2]. Nevertheless, in the 25 years since that tragedy there have been over forty failures of tailings dams worldwide. In all, they have caused the death of some 500 people and extremely serious socioeconomic and environmental damage. Many similar disasters had occurred before the Stava failure, such as the

Sgorigrad disaster of 1st May 1966 (Bulgaria), when a 220,000 $m^3$ mudslide spilled out of a failed tailings dam killing over 100 people and causing vast material and environmental destruction [3], or the Aberfan disaster in Wales in 1966, which caused the death of 144 people, mostly school children, or the Buffalo Creek failure in 1972 (U.S.A.), with 125 lives lost after 500,000 $m^3$ of black waste water were unleashed upon the local residents. In the 1998 disaster at Aznalcóllar (Spain), 2 million $m^3$ of tailings and 4 million $m^3$ of water polluted by heavy metals and toxic chemicals inundated a vast area in proximity of the Doñana National Park [4]. In January 2000 in the Baia Mare (Romania) gold mine, a breach in the tailings dam released some 100,000 $m^3$ of tailings contaminated with cyanide into the river system. This spill released an estimated 100 tonnes of cyanide, as well as heavy metals, particularly copper, into the rivers Someş, Tisza and finally into the Danube before reaching the Black Sea. In March 2000 torrential rains and melting snow from the slopes surrounding an artificial reservoir at a lead, copper and zinc mine in Baia Borsa (Romania) led to an unmanageable rise in the reservoir's water level. 20,000 tonnes of mineral waste were flushed into the River Viseu from the tailings dam. The accident led to the pollution of the River Vaser with minerals and heavy metals. This river is a tributary of the River Tisza that flows through Hungary and Serbia.

At the request of the Environmental Directorate-General of the European Commission, early this century the BRGM (*Bureau de Recherches Géologiques et Minières*) carried out a study on the management of mining, quarrying and ore-processing waste in the European Union [5]. The study highlighted two classes of environmental risks linked to mining waste: 1. Risks associated not only with potential polluting source (e.g. acidity and heavy metals in non-ferrous metallic ore) but also with the specific environmental context and the presence of vulnerable elements in the event of pollution. 2. Risks associated with the stability of tailings dams. The study also pinpoints that even if Europe currently occupies a modest position in world mining activity in terms of scale of production and mineral reserves, its role in the world mineral industry is not negligible as many companies in the sector are located in Europe. Moreover, although the mineral industry is modest within European borders, it plays a major role in the management of world resources in the international market. In addition, many engineering organizations and equipment manufacturers are located in Europe.

On 15th March 2006 the European Parliament and the Council of the European Union adopted the 2006/21/CE Directive concerning the management of waste from mining industries. The European Commission has calculated that in Europe the annual volume of ore-processing waste exceeds 400 million tonnes and has urged the member States to assess the potential catastrophic consequences of incidents similar to the Stava disaster: "*the environmental and socioeconomic repercussions of such failures*" – as the Commission declared – "*can last a long time whereas remedial interventions can imply very high costs, apart from being extremely difficult to implement*".

Furthermore, this Directive requires that all member States guarantee that operators do whatever is necessary to prevent, or reduce as much as possible, the negative consequences for the environment and human health resulting from the management of ore-processing waste. In addition, 2006/21/CE Directive stipulates that this includes the management of any stored waste, even after the closedown of the activities, and suggests the implementation of adequate monitoring and inspection measures, together with the census of all closed and abandoned structures. These monitoring activities should be carried out by specifically competent technicians.

Therefore, according to the European Commission, the European Parliament and the Council of the EU, university courses must be implemented which can produce qualified engineers so as to favour the transfer of technical knowledge and competence for the planning, construction and management of tailings dams. All those in charge of territorial management must also be made more conscious of the risks and of their own responsibilities. Due to the complexity of ore-processing waste management, young graduates who have just obtained their basic degree seldom have the required background; a Master's degree can be considered as the minimum qualification while a PhD is becoming more and more common [6].

The Stava 1985 Foundation (a non-profit organization) has been carrying out initiatives concerning active memory and education in order to prevent the occurrence of similar new disasters. The Foundation has also promoted and sponsored a 2nd level Master's Course at Trento University to prepare experts in analysis and management of geotechnical systems, including those related to tailings dams [7].

This Master's Course is named "SIGEO" (Italian acronym for Analyses and Management of Geotechnical Systems). Its lay-out, content and interdisciplinary approach are described, outlining the strong and weak points that have so far emerged. We hope that this experience may be an incentive for other academic institutions to organize similar courses or to set up a network for the implementation of an International Master's Course. The SIGEO 2nd level Master's Course was first proposed in the 2007-08 Academic Year.

## Goals

The general goal of the SIGEO Master's Course is to disseminate specific knowledge and competence in order to contribute to the mitigation of risks for the environment and man's health. These risks can be the result of erroneous predictions regarding the mechanical response of geotechnical structures. The specific aims are: i) preparation of qualified and responsible engineers; ii) census of existing risk conditions; iii) promotion of research activities; iv) active memory and lessons learnt from past mistakes.

i) It is a specific aim of this Master's Course to disseminate knowledge in the fields of civil and environmental engineering, earth sciences, engineering geology, sociological and economic sciences and business organizations, indeed, among all people involved in the study of geotechnical systems. The people targeted should study and understand the planning choices and processes which control the safety and efficiency of geotechnical structures as well as the sustainability of their design. Furthermore, this Master's Course aims to facilitate the dialogue between technicians and stimulate an interdisciplinary approach to the problem by providing a sound methodological basis for the optimal management of organizational and relational processes. In this way synergy may be promoted between populations, technicians and managers for maintaining safety and managing risk situations in the best possible way. This Master's Course provides students with a technical-professional qualification so that they will be capable of carrying out co-ordination, construction and monitoring projects on geotechnical structures as well as in-depth knowledge of the responsibilities related to managerial posts. One of the main characteristics of this Course is the link between technical, legal, environmental and economic knowledge.

ii) The SIGEO Master's programme is also based on training courses during which students acquire direct experience in the identification of risk scenarios and the interventions for their elimination. In this way the Course is also a tool in the census of geotechnical structures, including sites for storing mine tailings, which show risk conditions, in Italy and in other European Countries.

iii) This Master's Course means to be the meeting point between experts in scientific disciplines, people interested in acquiring high-level competence by analysing actual case studies. In this way it can also be an incentive for implementing research in forecasting and preventing risk conditions.

iv) Another goal of this Course is to maintain a firm and constant connection with the surrounding territory, considering also actual cases that can be proposed and analysed by the Master students themselves. Besides Italy, the context is directed mainly to East-European and developing Countries, where most mining activities are now taking place, together with related problems of mine waste disposal.

## Organization

In the first 2007-08 edition, the SIGEO 2nd level Master's Course was proposed by three Italian academic institutions: Trento University, Turin Polytechnic and Modena and Reggio Emilia University, which shared the goals of the initiative and made several of their professors and researchers available, with the patronage of the Stava 1985 Foundation. Teaching activities were co-ordinated by the Council of Professors, made up of eight university teachers from various disciplinary sectors. In order to be sure that this Course provided the qualifications required by the sponsors, a Board of Directors was also established, made up of nine members representing civilian society, industry, public administration, planning agencies, service industries and financial and insurance companies. This Board of Directors has had the task of identifying the strategic framework of the Master's Course and passing it on to the Council of Professors.

## Educational activities

This Master's Course was proposed to 5-year graduate students in Civil or Environmental Engineering, Earth Sciences, Architecture and Forest Sciences. The Course was based on a total commitment of some 1,500 hours, subdivided into: 1,075 hours of teaching activities, out of which 344 hours of lessons and 731 hours of individual study, 300 hours of training courses and 125 hours for preparing the final thesis. Teaching activities were distributed over three modules.

Module 1 was dedicated to “Choices and Constraints”. In 225 hours the following topics were developed:

- identification of the social and economic variables which guide or condition planning choices;
- assessment of the impact of specific choices on sustainable development;
- understanding of the role of technicians in charge of choices;
- analysis of planning processes;
- analysis of emergency situations.

In detail, four courses were proposed: 1) social aspects of economics, 2) people and behaviour, 3) management of complex situations, 4) prevention and protection.

Module 2 (225 hours) concerned “Basic Technical/Scientific Knowledge” and its purpose was to:

- disseminate the fundamental concepts of the disciplines involved in the study of geotechnical systems;
- provide students with a common technical language and a level of knowledge common to all participants, regardless of their individual provenance and formation.

The basic courses proposed were: 1) general geology, 2) fluid mechanics, 3) soil mechanics, 4) geomorphology.

In Module 3, “Interventions and Interactions with the Physical Environment”, notions and concepts for understanding planning choices, processes which govern the safety and efficiency of engineering structures and mechanisms through which a structure interacts with the environment. All this was carried out by developing the following aspects:

- knowledge of the physical and mechanical variables which control planning choices;
- knowledge of the physical and mechanical processes which control the efficiency of engineering structures;
- knowledge of the appropriate tools for the study of processes which control the efficiency of engineering structures;
- knowledge of the mechanisms through which an engineering work interacts with the environment;
- forecasting and prevention of emergency situations.

Module 3 consisted of 625 teaching hours distributed over five courses: 1) hydrogeology and hydrology of saturated and unsaturated soils, 2) soil and water pollution, 3) field investigations, 4) analysis of failure conditions, 5) monitoring and control.

The students’ training courses took place (either individually or in a group) in companies proposed by the students themselves or the Council of Professors. In particular, students were invited to propose case studies of their own interest, for which they were requested to identify possible risk scenarios and assess planning solutions for the implementation of safety measures. The goal of the training courses was to apply the knowledge acquired in the teaching modules and develop the capacity to recognise and solve problems.

The problems analysed during the training courses were subsequently studied in-depth during the Master thesis.

The various topics making up the syllabus of the Master's Course were dealt with by 39 university teachers.

In order to better disseminate knowledge and offer further opportunities for professional formation, technical seminars and excursions were proposed also for private consultants and staff from public administrations. These people were allowed to enrol in single courses of the Master's formation activities (Fig. 2).


Fig. 2 – A technical seminar for engineers and geologists at the Documentation Centre of the Stava 1985 Foundation

## Costs

The organization and management of the SIGEO Master's Course cost approximately € 100,000, of which only 25% was acquired from students' fees. The Master's enrolment fee was € 5,000, but scholarships up to € 2,500 were also granted. The remaining funding for the Course was provided by the Autonomous Province of Trento, the Municipality of Tesero, the Edison Company, the Lion's Club, and the "Cassa Rurale di Fiemme" Bank.

## Results

With respect to the Master's prefixed goals, the results attained are as follows:

a) The Course was attended by 8 students, of which 6 males and 2 females. Four of them had a degree in Civil Engineering, three in Engineering for the Environment and Territory, one in Earth Sciences. Only five out of eight completed the course and obtained the Master's title. Five in-depth seminars were also proposed: i)

Analysis and mitigation of landslide risks; ii) The tailings dam of the Zelazny Most copper mine (Poland); iii) Geotechnical aspects in planning and constructing river embankments; iv) Embankment collapses in alluvial plains due to siphoning; v) Geomorphological hazards, impacts and risks: concepts, assessment and mitigation with particular attention to seismic risk. On the whole, over 50 persons participated.

b) Six out of the seven training courses and Master theses were dedicated to the study of actual cases of instability conditions affecting both natural and artificial slopes.

c) The results of one of the Master's theses were presented at an international congress.

d) Four technical excursions were carried out, of which three on sites where disasters took place: the Vajont landslide and reservoir (1910 dead), the Stava tailings dams (268 dead), the Pontesei landslide (1 dead) which anticipated the Vajont catastrophe, the river flow-control systems on the River Po catchment basin.

## Strong and weak points

Regarding the results of the SIGEO Master's Course, several strong and weak points were identified.

Strong points:

1. The SIGEO Course attracted candidates from various Italian regions, thus demonstrating that students are ready to move about when they are motivated and that the topics proposed are of general interest, and not only for the students more emotionally involved because they reside near disaster locations such as Stava and Vajont.
2. It also attracted students from different disciplinary areas: civil engineering, environmental and territorial engineering and earth sciences, thus showing the interdisciplinarity of the topical subject of analysis and management of geotechnical systems.
3. It attracted both male and female students; therefore, it did not show sexual discrimination.
4. The interdisciplinary subjects were highly appreciated by the students. In particular, keen interest was shown for the social and industrial management themes, which are not usually dealt with in their respective degree courses.
5. Finally, this Master's Course put together 39 academic teachers from various Italian universities. The Course has been an important meeting point facilitating experience exchanges and network organization.

Weak points:

1. The number of students enrolled was low since many young graduates do not yet perceive the demand for professional consultants competent in analysis and management of geotechnical structures.

2. Funding was required from outside the university. Indeed, with the lack of job opportunities, fees applied to enrolling students cannot be high; therefore, they are not sufficient to cover all organizational costs.
3. It was rather difficult to put together the necessary funds from both private enterprises and public boards.

## Final remarks

By considering the explicit requirement of the EU 2006/21/CE Directive to employ engineering staff with specific knowledge for construction and management of tailings dams, to date there is not sufficient awareness and resolve among private enterprises and public boards in investing in advanced technical education.

A solution could be the activation of an international 2nd level Master's Course proposed by a consortium of European universities, which would allow access to EU funding. For this purpose the Erasmus Mundus programme provides Scholarships and Fellowships to highly educated students and academics from all over the world. This programme can be designed and implemented by a consortium of European universities from at least three different countries. Consortia may also include universities from other parts of the world.

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