## ENGINEERING GEOLOGY AS AN INTERDISCIPLINARY FIELD

### Introduction

"Engineering geology is an interdisciplinary field in which pertinent studies in geology and other geosciences areas are applied toward the solution of problems involved in engineering works and resources uses" (Sitar et al, 1983; Goals for basic research in engineering geology: Report of NSF Workshop, St. Helena, CA).

The Association of Engineering and Environmental Geologists (AEG; www.aegweb.org) defines engineering geology as "[The] application of geologic data, techniques, and principles to the study of naturally occurring rock and soil materials or subsurface fluids. The purpose is to assure that geologic factors affecting the planning, design, construction, operation, and maintenance of engineering structures and the development of groundwater resources are recognized, adequately interpreted, and presented for use in engineering practice".

"Engineering Geology is the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of man as well as to the prediction and of the development of measures for prevention or remediation of geological hazards." (International Association of Engineering Geologists, IAEG statutes, 1992). See also several definitions of engineering geology on the web: http://en.wikipedia.org/wiki/Engineering_geology. What are engineering geologists? http://en.wikipedia.org/wiki/Engineering_geologists

Ignorance of geology (or a poor assessment of geology), and of geologic hazards (floods, volcanoes, earthquakes, etc.) cannot be tolerated in civil and environmental engineering projects. Failure to characterize the geological site and geological setting has too often resulted in needless structural damage, environmental disasters, or loss of life. In almost all cases, proper consultation with engineering geologists or geological engineers could have prevented such problems. You should be aware that an adequate geological site evaluation and exploration program is vital to a project and represents only a small percent of its overall cost. It should be thought of as an investment in a product with a useful life rather than as a means for generating short-term profits. An adequate geological site evaluation and exploration program is one of the best insurance for safeguarding against unforeseen failure and catastrophic losses due to tangible material loss and to liability and litigation.

Engineering geology represents a vital link between the two more conventional fields of *engineering* (which is concerned with putting scientific knowledge to practical use) and *geology* (which is concerned with the physical nature and history of the Earth). Engineering geology provides a means to *appreciate* and *identify* geologic features that could have short and long-term consequences to the overall performance of engineering structures and projects. It is also a study of how we are affected by geological phenomena, and how we can affect the environment and trigger geologic processes.

Engineering geology requires a well-balanced training with courses in classical geology (that are mostly qualitative) and courses in engineering fundamentals (that are mostly quantitative). Undergraduate students are exposed to engineering geology in geology or civil engineering curricula. In civil engineering, engineering geology is often offered as an introductory lecture to other courses in geotechnical engineering such as soil mechanics and rock mechanics. Geotechnical engineers with geologic emphasis in their upper-class studies will be called G*eological Engineers*. On the other hand, geologists who have later received education and practice in engineering disciplines will be called *Engineering Geologists.* In general, engineers are involved in the design of engineering works whereas geologists and engineering geologists supply engineers with geologic data and insure that geologic factors are properly considered.

Communication is essential between engineers and geologists, as they often have to work together. Thus, cross training is necessary for all civil engineers and for all geologists who intend to practice in environmental or engineering geology. The civil engineer should have at least one course in geology that provides familiarity with the basic Earth materials, processes, an awareness of change through time, and ideally how this knowledge applies to the success of an engineering project. Only this minimal training can permit communication with geologists who will perform the actual site characterization. Engineering or environmental geologists should have a course in applied geology that emphasizes applications of their science to engineering practice. Geology students who wish to practice in environmental/engineering careers should have a good dose of courses in mathematics and/or engineering that involve quantitative reasoning because this background is necessary in order to communicate with engineers whose training is primarily quantitative rather than descriptive and to appreciate the problems with which the engineer is confronted.

**Rocks and Soils**

Engineering geology deals with two types of earth materials: *rocks* and *soils*. Both materials are used in themselves as raw sources for construction materials (aggregates, construction stones, decorative stones, etc.). They can also be used as foundation materials to support foundations for bridges, towers, high-rise buildings, residences, dams, and offshore structures. The behavior of those structures is partly determined by the proper selection and sizing of man-made materials such as concrete and steel, and partly determined by the geology and the properties of the underlying rock or soil on which the structures must rest.

Rocks and soils become the engineering material in surface excavations (quarries, canals, highway and railroad cuts, surface mines, gravel pits, etc.) and underground excavations (tunnels, caverns, hydroelectric plants, pump storage plants, gas and water storage facilities, waste repositories, military shelters, etc.). Here, the performance (short and long term) of the structures depends on the rock/soil type as well as the rock/soil quality, strength, deformability, permeability, etc. Rocks and soils are also critical factors in determining the extent of leakage and contaminant transport and in assessing the potential of environmental problems associated with the disposal of various types of waste (chemical, nuclear, etc.). Finally, rocks and soils are important in the investigation and development of surface and ground water resources.

From an engineering point of view, a *rock* is an aggregate of mineral grains that are connected by strong and permanent forces that cannot be separated by slight mechanical means. On the other hand, a *soil* is an aggregate of mineral grains that can be separated by slight mechanical means. In general, soils are formed from the erosion or weathering (mechanical, chemical) of rocks. The weathering zone (i.e. the volume of weathered rock) can be a few feet thick in arid areas and several hundred feet thick in tropical (hot and humid) areas. A rock that is not weathered is called "fresh" (weathering grade I), whereas a fully weathered rock is called a soil (weathering grade VI). Obviously, there is a wide range of earth materials that fit in between those two extremes. Some of them have properties that are more rock dominant whereas others have properties that are more soil dominant; these materials are called *rock-like soils* or *soil-like rocks*. As civil engineers, on a given project, we need to know the vertical and lateral extent of the weathering zone, the different grades of weathering, and how deep the fresh unweathered rock is located.

You should be aware that the engineering definitions of soils and rocks are not universal and are not always accepted by geologists. For a geologist, the term *rock* means all the material found in the Earth's crust regardless of the degree of bonding between the mineral grains, whereas the term *soil* is reserved for the upper part of the ground surface that is supporting the vegetation. Peodologists and agronomists that are only concerned with the upper layers of soils bearing forest and agriculture have also adopted these definitions.

The communication problem between geologists and engineers exists also with regard to rock classification. In general, geologists classify rocks into three major groups: igneous, sedimentary, and metamorphic. Rocks are classified from a genetic point of view, i.e. how they were formed. Each rock group is further divided into sub-groups based on the grain size, the rock texture, etc. On the other hand, engineers are more interested in how rocks behave in practice. They classify rocks based on their performance in various engineering applications such as drilling, blasting, tunneling, rock/dam interaction, slopes, etc.

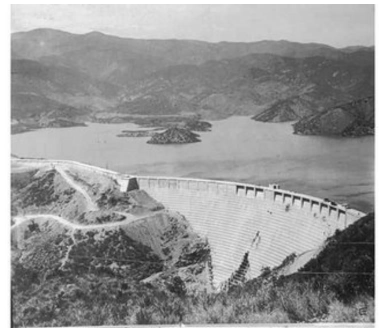
See ASTM D 653-97 for standard terminology related to rock, soil, and contained fluids.

**Potential Geologic Problems**

Several examples of geologic problems associated with some areas of CEAE engineering practice are listed below.

Foundations for bridges, towers, high-rise buildings, residences, dams, and offshore structures:

- Settlement (uniform or differential)
- Settlement due to soft layers and compressible soils
- Settlement due to fluid withdrawal



- Settlement due to uneven ground composition (landfills, cemeteries, sewers, etc.)
- Subsidence associated with underground mining
- Subsidence into natural caverns (caves, karsts, etc.)
- Dam movement due to unstable foundation and abutments
- Frost heave and solifluction
- Heaving and settling due to swelling ground
- Liquefaction
- Scouring (erosion) of bridge pier foundations
- Deterioration by acid waters

Slopes and surface excavations for canals, highways, railways, pipelines, penstocks, dam abutments, open pit mines, quarries and trenches, landfills.

- Landslides (including rock falls, flows, creep, both natural and man-induced)
- Block movement by sliding or toppling
- Block movement during blasting or earthquakes
- Stability problems of earth and rockfill dams
- Drainage and dewatering problems
- Piping, liquefaction
- Piercing of landfill lining and ground contamination

Underground Excavations for tunnels, mines, underground chambers, hydroelectric plants, pump storage plants, gas and water storage chambers, subsurface space, and military shelters.

- Caving and collapse of a section
- Water problems
- Squeezing and swelling ground
- Rock bursts
- Leakages of stored material (toxic and non-toxic)
- Toxic gases (radon, methane, sulfur dioxide) and dusts (asbestos)
- Disposal of excavated ground

Although the methodology used for the previous projects differs from one to the other, all these projects have three basic similarities. First, they all require an evaluation of the site geology, i.e. rock types, extent of each rock unit, extent and type of weathering, etc. This is usually done by conducting detailed site exploration and investigation using surface mapping, boreholes, trenches, or geophysical survey. Site exploration and investigation is usually conducted in several steps (preliminary, advanced, etc.). Second, all the aforementioned projects require an assessment of the engineering properties (strength, deformability, permeability, etc.) of the soils and rocks involved in the projects. This is done by testing rock or soil samples in the laboratory and by field testing. Finally, engineers need to take into account possible geologic hazards and their impact on existing and future structures. In general, geological hazards can be divided into hazards from geological materials (reactive minerals, asbestos, gas hazards), and hazards from geological processes (volcanoes, earthquakes, landslides and avalanches, subsidence, floods, coastal erosion).

**Geology**

Geology is the science of the Earth, its composition and structure, its history, and its past plant and animal life. Modern geology developed in the late 18th century as a result of the need for a practical knowledge of rocks and minerals in the mining industry.

In a nutshell, geology is divided into two major groups. The first, called *Physical Geology* deals with the materials that constitute the Earth (soils and rocks), the structures and surface features of the Earth, and the processes that created these structures. The second group called *Historical Geology* deals with the history of the Earth.

Geology is further divided into a number of branches according to the subject matter that is covered or to the industrial or commercial applications. Subject matters of possible interest to engineers include:

- *Petrology*: systematic study of rocks and their origin. It consists of *Petrography* (identification, description, and classification of rocks) and *Petrogenesis* (study of origin of rocks);
- *Mineralogy*: study of rock constituents or minerals;
- *Crystallography*: deals with the atomic structure of minerals and their external appearance;
- *Geochemistry*: study of the chemistry of rocks;
- *Geomorphology*: study of landforms, their origin and development;
- *Stratigraphy*: study of layered rocks, mostly those of sedimentary origin;
- *Structural Geology*: deals with the position of rock bodies, their deformation, and fracturing;
- *Geophysics*: application of principles of physics to the study of the Earth. It consists of *Geomagnetic* (study of Earth's magnetic field) and *Seismology* (study of earthquakes); and *Geodesy*: study of the form and size of the Earth;
- *Oceanography*: study of oceans and basins;
- *Paleontology*: study of life of past geologic periods and evolution of plants and animals;
- *Engineering Geology*: geology and engineering;
- *Hydrogeology, Hydrology*: study of underground and surface water.

Other fields include: economic geology, agricultural geology, mining geology, petroleum geology, military geology, etc.

## Course Objective

The main objective in CVEN 3698 is to teach you how to *appreciate* and *identify* geologic features that could have short and long-term consequences to the overall performance of various engineering structures and projects that you might encounter in your engineering career. In order to do that, you will have to learn some fundamentals of geology. However, it is not the intent to make geologists out of you (this could not be done in one semester).

At times, the terminology used in class will appear to be somewhat overwhelming and confusing. It can be, and there is not much that can be done about it. If you are confused and/or need more information, do not hesitate to ask as many questions as possible and/or to consult a dictionary of geological terms (see engineering or geological sciences library).

You will find that most of the homework assignments will be group projects in order to encourage you to work together, exchange ideas, and above all, realize that in engineering there is often more than one correct solution to a given problem. Most assignments deal with real problems and require thinking and time.

**Exercise # 1** (Due January 27, 2019)

This exercise is about reading of a case study where a catastrophic project failure occurred despite superb engineering.

This exercise is designed to give you a better understanding about the value of engineering geology. At the completion of this exercise, you should realize the following:

a) The importance of geology to civil engineering
b) The importance of an interdisciplinary approach to design
c) Why you need to understand the terminology of earth materials
d) Why you need to know how to obtain geological information
e) Why importance of site characterization equals that of design
f) Why the concept of "change through time" must be understood

Read *ALL* of the following questions before proceeding. Then, read the article entitled "*Vaiont Reservoir Disaster*" by G. A. Kiersch, published in Civil Engineering (library call number: TA 1 C 49), Volume 34, pp. 32-39,1964. This article is available electronically from the course web site (see assignment for January 27). Then, write the answers to the questions as you find them.

1) Was the dam itself of sound design and a product of quality construction?

2) Compose a list here of the geological terms that you encounter in this reading that you could not define and explain in a test situation.

3) How much time elapsed between completion of the dam and the occurrence of the devastating slide detailed in this paper?

4) Were the designers aware that this valley was landslide-prone before they built the dam? What feature of Fig. 1 suggests an answer?

5) Read the description of the Malm Formation under "The geologic setting". List all words here that you are certain are significant in conveying to the reader a problem with respect to slope stability.

6) Examine Fig. 4. Note the wide U-shaped profile of the upper (outer) portion of the valley as opposed to the steep V-shaped profile of the lower (inner) portion of the valley. Can you explain why this form exists? Is the form meaningful in terms of the dam?

7) Was the occurrence of the slide a complete surprise or was there some forewarning? If it was not a surprise, list the times and types of forewarning that were available.

8) A slide occurred in 1960 near the dam. Why didn't this slide cause a disaster? In what way might this slide have instilled a false sense of security into the minds of engineers who managed the reservoir?

9) Use graph (or engineering) paper or the computer, make a graph of rate of creep in cm/day (y-axis) vs. time (x-axis) given on page 36. Mathematically, what type of function is described by this graph? If you wish to modify your answer to "7" above, do so here.

10) If you ignore the labels and the caption of Fig. 5 and simply look at the geological formations, is there anything that tells you that this valley constitutes a hazardous landslide-prone site?

11) Does excellence in engineering design guarantee final success of a project? If not, what additional resource(s) are needed?

12) If a liability suit evolved from this failure, who would be liable?

**Exercise # 2**

Select an article or report that provides an interesting case study and clearly emphasizes the role of geology in an engineering context. Note that actual case studies on which you have worked in design projects or on internships are good as well as some in-house company publications. On-going projects in the Denver/Boulder area can also be reported. Your instructor must approve the case study by **February 27, 2019.** This is an individual project.

Prepare a written report for each case study. It should be typed and not exceed 10 pages (1 space, 12 font) including illustrations (Figures, Tables). The reports are due by **April 26, 2019**. Each case study will be presented in class at the end of the semester. Each oral presentation (Power Point format) should not exceed 15 minutes including Q&As.

This assignment represents 10% of your final grade. It will give you the opportunity to explore a real engineering case study, understand it, and present it to your peers.