Module 1

FUNDAMENTALS OF GEOENVIRONMENTAL ENGINEERING

A) Scope of geoenvironmental engineering

Any project that deals with the interrelationship among environment, ground surface and subsurface (soil, rock and groundwater) falls under the purview of geoenvironmental engineering (Fang and Daniels 2006). The scope is vast and requires the knowledge of different branches of engineering and science put together to solve the multi-disciplinary problems. A geoenvironmental engineer should work in an open domain of knowledge and should be willing to use any concepts of engineering and science to effectively solve the problem at hand. The most challenging aspect is to identify the unconventional nature of the problem, which may have its bearing on multiple factors. For example, an underground pipe leakage may not be due to the faulty construction of the pipe but caused due to the highly corrosive soil surrounding it. The reason for high corrosiveness may be attributed to single or multiple manmade factors, which need to be clearly identified for the holistic solution of the problem. The conventional approach of assessing the material strength of the pipe alone will not solve the problem at hand.

A lot of emphasis has been laid for achieving a “green environment”. Despite a lot of effort, it is very difficult to cut off the harmful effects of pollutants disposed off into the geoenvironment. The damage has already been done to the subsurface and ground water resources, which is precious. An effective waste containment system is one of the solutions to this problem. However, such a project has different socio-economic and technical perspectives. The realization of such projects require the contribution of environmentalist, remote sensing experts, decision makers, common public during its planning stage, hydrologists, geotechnical engineers for its execution stage and several experts for management and monitoring of the project. The totality of the problem can be visualized under the umbrella of geoenvironmental engineering. Therefore, the real challenge for a geoenvironmental engineer is how well he can integrate the multi-disciplinary knowledge for achieving an efficient waste containment.

As mentioned earlier, in most parts of the world, damage has already been done to the geoenvironment and groundwater reserves due to indiscriminate disposal of industrial and other hazardous wastes. Owing to the excessive demand, it becomes important to remediate and revive the already polluted geoenvironment and groundwater. A geoenvironmental engineer has a great role to play for deciding the scheme of such remediation practice. A lot of concepts from soil physics, soil chemistry, soil biology, multi-phase flow, material science and mathematical modelling, need to be taken for planning and execution of an efficient remediation strategy. Therefore, it is essential for the geoenvironmental engineer to think out of the box, to an extent that the knowledge can help him visualize the problem better and suggest efficient solution. Else, the solution to such problems becomes a trial and error process or rather, learn from mistakes and rectify. Since such projects are cost intensive one cannot afford to take too much of chances.

Another important issue is the reuse and recycling of waste materials, which reduces the burden on our environment manifold. A very good example is exploring the possibility of mass utilization of fly ash for geotechnical applications. However, while using waste materials for meaningful applications there are issues such as short term and long term impact, which is a governing factor for deciding its selection as a viable material. Although, short term behavior can be assessed using planned laboratory evaluations it often becomes difficult and complex for understanding the long term behavior. The scope of geoenvironmental engineering is to simplify the process of understanding the behavior and resort to reliable predictions and estimations. This would require a thorough knowledge on material science and chemistry and the reaction it undergoes with time. This is indeed a tough task, but needless to say, such challenges make this subject quite interesting.

The frequent occurrence of landslides especially during rainy season has drawn the attention of researchers and practicing engineers. The conventional slope stability analysis is partially helpful in understanding the problem. A wider perspective of the problem would be to include factors such as infiltration and seepage of rain water through the slope. Such factors are going to add on to the instability of slope. The scope and challenge for the geoenvironmental engineer is to couple the geotechnical, geological and hydrologic concepts to explain rainfall induced slope failure. Construction of flood protection works such as embankments and levees also comes under the purview of geoenvironmental engineering. Unless a thorough hydraulic study is conducted, any geotechnical measures for flood protection would prove to be futile. This is specifically true for large rivers and for meandering sections.

Geoenvironmental engineering is more research oriented and new concepts and methodologies are still being developed. Therefore, this particular course intends to introduce different avenues and overall scope of geoenvironmental engineering to the reader. The course would highlight the uncertainties and complexities involved and the wide research potential of the subject. Special emphasis has been laid on the basics of soil-water interaction, soil-water-contaminant interaction, which are essential for understanding the impact of geoenvironmental contamination, its minimization and remediation.

B) Multiphase behavior of soil

Conventional or classical soil mechanics assumes soil media to be completely water or air saturated. This is a typical example of a two phase media consisting of soil solids and water/air. The assumption of two phases considerably simplifies the mathematical quantification of the complex phenomena that take place in porous media. Off late, geotechnical and geoenvironmental engineering problems require the concept of three or multiphase behaviour of soil for realistic solution of several field situations. For example, a partially saturated soil is a three phase porous media consisting of air, water and soil. The three phases result in transient and complex behaviour of unsaturated soil. Such cases are encountered while designing waste containment facility where flow characteristics of unsaturated soil need to be determined. When it comes to soil-water-contaminant interaction there are multi-phase interactions involved. The migration of non-aqueous phase liquid (denoted as NAPL) through porous media is a typical example. Fluidized bed, debris flow, slurry flow, gas permeation through unsaturated soil media are some problems where multiphase behaviour becomes important. Such studies are handy while designing remediation scheme for contaminated soil and groundwater, which are very important issues for the geoenvironmental engineer to solve. Understanding the complex interaction of different phases is challenging and has paved way for the study of multiphase behaviour of porous media. Such a realization has generated a lot of interest in the research fraternity for developing experimental and mathematical procedures for clearly delineating the phenomena in multiphase porous media.

C) Role of soil in geoenvironmental applications

All civil engineering structures are ultimately founded on soil and hence its stability depends on the geotechnical properties of soil. Conventional geotechnology is more concerned about rendering soil as an efficient load bearing stratum and designing foundations that can transfer load efficiently to subsurface. Apart from this, soil is directly related to a number of environmental problems, where the approach should be a bit different. Consider the case of groundwater recharge as shown in Fig. 1.1. The infiltration and permeation property of homogenous or layered soil mass above water table decides the rate of recharge. In this case, a geotechnical engineer has to work closely with hydrogeologists for deciding different schemes of artificial groundwater recharge.

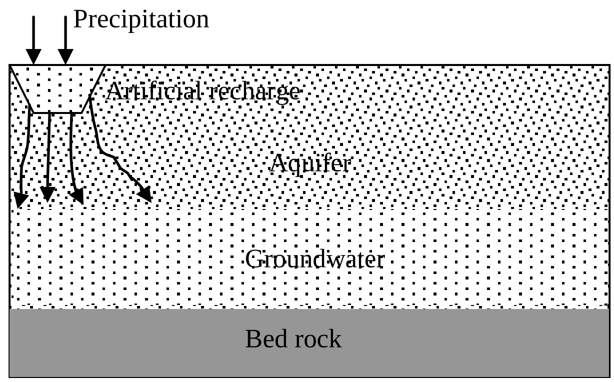

Fig. 1.1 Artificial groundwater recharge

Consider the case of waste dumped on ground surface. During precipitation, water interacts with these wastes and flow out as leachate. When the leachate flows down, soil act as buffer in retaining or delaying several harmful contaminants from reaching groundwater. Such a buffering action obviously depends on the texture and constituents of soil mass. While designing a waste containment facility, the role of soil in such projects is enormous. A coarse grained soil with filter property is required for leachate collection where as a fine grained soil is required for minimizing flow of leachate. These are two entirely different functions expected from soil in the same project. The cap provided for waste dumps also necessitate the use of specific type of soils with the required properties. The amount of water that infiltrates into the waste below is minimized by soil used in such caps. Special type of high swelling soils is used as backfills for storing high level radioactive waste in deep geological repositories. Another important geoenvironmental problem, namely, carbon sequestration uses the geological storage capacity for disposal of anthropogenic CO_2 to mitigate the global warming. Therefore, soil plays a very vital role in geoenvironmental projects and the property by which it becomes important is problem-specific.

D) Importance of soil physics, soil chemistry, hydrogeology and biological process

Soil physics is the study of the physical properties and physical processes occurring in soil and its relation to agriculture, engineering and environment. It deals with physical, physico-chemical and physico-biological relationship among solid, liquid and gaseous phase of soil as they are affected by temperature, pressure and other forms of energy. Hence, the knowledge of soil physics becomes important for solving geoenvironmental problems. The concepts of soil physics is used for determining the transport of water, solute and heat (matter and energy) through porous media, which is important to solve the problems related to subsurface hydrology, groundwater pollution, water retention characteristics of soil, improving crop production, rainfall induced landslides etc. Soil physics is mostly quantitative and mathematical in nature and requires the knowledge of soil physical properties. The important soil physical properties include soil texture which deals with the particle gradation; soil water which include mechanisms such as retention, infiltration, run off, permeation, evaporation, transpiration, irrigation scheduling etc; soil aeration to take into account exchange of gases such as oxygen and carbondioxide by plant roots and microorganisms present in the soil. While defining these physical properties of soil, it is very important to consider representative elementary volume (REV) which is required to describe or lump the physical properties at a geometrical point (Scott 2000). REV therefore describes mean property of the volume under consideration.

Soil chemistry is the study of chemical characteristics of the soil and is one of the important information required for many of the geoenvironmental problems. The emergence of discipline “soil chemistry” began when J. T. Way (father of soil chemistry) realized that soil could retain cations such as NH^{4+}, K^{+} in exchange for equivalent amounts of Ca^{+2} (Thomas 1977). This means that soils act as ion exchangers. This aspect is vital for using soil in waste management application. The contaminants leaching out of the waste dumps find its way to groundwater flowing past the soil porous media. The concentration of contaminant at a distance away from the source for a given time is fully governed by the chemical interaction of contaminant and the soil. There are several simple and complex chemical reactions that may take place in soil-water system depending upon the prevailing favourable condition. An example is the phenomenon of solubility and precipitation as governed by the pH of the soil-water-contaminant system. The knowledge of soil chemistry is important to understand interactions between soil solids, precipitates and pore water, including ion exchange, adsorption, weathering, buffering, soil colloidal behaviour, acidic and basic soils, salinity etc. There is an interesting story which resulted in the effects of soil acidity and alkalinity. The investigation on poor crop productivity in eastern United States in early 1800's lead to the understanding of high soil acidity, which was regulated by the addition of lime. This resulted in high yield of crops. Similarly the deleterious condition of soil due to high alkalinity was realized and investigated in detail. After 1920's the understanding on structural soil chemistry and soil organic chemistry improved a lot. The acidity and complexation potential of organic matter was appraised. A lot of chemists researched on the structure and reactivity of water on soil mineral surface. These and many other findings lead to the development of soil chemistry and today it is one of the important branches of science required to explain several phenomena in geoenvironmental engineering.

Understanding subsurface for geoenvironmental problems requires extensive knowledge of hydrogeology. Hydrogeologic parameters influence a lot on how a waste containment facility performs over its design life. Therefore, while deciding the location for such facility it is important that the subsurface hydrogeology condition is fully explored and studied. Different in-situ methodologies are used for remediation of a contaminated site. For effective functioning of such methods one has to study the hydrogeological aspects of the site. Hydrogeologists play a vital role in locating groundwater aquifer, its management and optimal extraction. Efficient watershed management by artificial recharge is possible only if the hydrogeology of a particular area is known. The knowledge of hydrogeology is also required for understanding the direction of groundwater flow. This is often required for assessing the extent of contamination occurring due to a particular source of pollution and for risk assessment.

Off late a lot of emphasis is laid on biological processes occurring in soils. Initially, agriculturists were more bothered about this subject. But the subject has caught the attention of many researchers due to its potential in solving different geoenvironmental problems. For example, some type of microorganisms such as Pseudomonas aeruginosa is used for remediation of hydrocarbon contaminated site. It is very essential to understand the rate of such reaction and the impact of such remediation. A lot of researchers worldwide are working on this interesting problem. Biological process in soils is dependent on temperature and climatic condition of a place, which need to be studied in detail. The soil biological process is found to influence the exchange of greenhouse gases between soil and atmosphere and many other soil physical parameters such as water retention characteristics.

E) Sources and type of ground contamination

Solid, liquid and gaseous waste forms contaminates subsurface and groundwater due to indiscriminate disposal. Solid wastes come from municipal, domestic and industrial sources. Municipal wastes amounts to around 50 percent of the total wastes produced. Household, hospital, agricultural wastes forms part of municipal wastes. Returning these wastes to soil is considered to be a low cost option. Abandoned e-waste, batteries, vehicles, furniture, debris from construction industry is considered as solid waste and is produced from both urban and rural areas. Large scale industrial development produces huge quantities of hazardous waste and the sources are iron and steel industries, packaging factories, paints, dyes, chemicals, glass factories, fertilizer and pesticide industries, mine excavation waste etc. Coal mining, radioactive fuel mining, petroleum mining and thermal power plants generate hazardous solid waste that requires effective management.

The main source and type of hazardous liquid waste include industrial waste water contained in surface impoundments, lagoons or pits. It is also produced from municipal solid refuse and sludge that are disposed on land. If not handled properly sewage becomes an important source of liquid waste that has undesirable effect on environment. Petroleum exploration leaves waste brine solution which needs to be managed to prevent groundwater pollution. Liquid waste emerges due to mining operation which is hazardous. A typical example is acid mine drainage from dumped mine wastes.

Some of the gaseous waste includes NOx, CO, SO_2, volatile hydrocarbons etc. Chemical reaction may take place in air producing secondary pollutants. SO_2 combines with oxygen to produce SO_3, which in turn combines with suspended water droplets to produce H_2SO_4 and fall on ground as acid rain. Natural breakdown of uranium in the geoenvironment emits cancer causing radon gas into atmosphere.

F) Impact of contamination on geoenvironment

In most of the cases, wastes are disposed off indiscriminately in low-lying areas without taking adequate engineering measures to effectively contain it. This results in a highly unhygienic and unhealthy environment leading to breeding of pests, mosquitoes and several harmful microorganisms. Many of the emerging diseases found these days are direct impact of geoenvironmental contamination due to wastes. During precipitation, or groundwater coming in contact with these wastes generates contaminated water called leachate that can travel far field and pollute the surface and groundwater resources. Many of the harmful heavy metals can also travel along with the leachate if it is not contained properly. Some of the solid waste such as excavation and mining waste, fly ash (wet and dry) from thermal power plants requires large area of land for its storage as wastes. This in turn would interact with rain water and can cause contamination. Several harmful heavy metals well above the contamination limit can enter the life cycle of organisms living in close proximity with such disposal sites.

One of the complexities of contamination impact is its long term effects without a chance for realization. Most of the impacts are realized much later from rigorous studies, and by the time the damage would have been done. Hence, remediation becomes a tedious and cost-intensive affair. This makes geoenvironmental engineering a challenging and much needed subject. There is a need to focus on research that would help to predict and minimize the long term impact of indiscriminate and mismanaged waste contamination.

G) Case histories on geoenvironmental problems

Use of readily available local soil instead of expensive commercial soil (like bentonite) for waste management

Engineered waste management scheme necessitates the construction of highly impermeable barrier so that waste disposed on it does not find its way to ground water resources. Mostly these barriers are made of high plastic clays which are commercially available. This would considerably increase the cost of such geoenvironmental projects. Exploring the possibility of using local soils for such applications, therefore, becomes an important geoenvironmental problem. Any success in this direction would add to the economy of the project. This in turn would result in sustainable development of such very important project. The following research paper is an excellent case history of finding solution to one of the geoenvironmental problems.

Taha and Kabir (2005) have explored the possibility of using tropical residual soil for waste containment, which is readily available over a considerable part of peninsular Malaysia. Hydraulic conductivity is used as the criterion for evaluation of soil suitability for the said application. The soil was compacted at different water content and compaction effort and then permeated with de-aired tap water. The results of hydraulic conductivity test indicates that the required flow of less than 10^{-9} m/s can be achieved by using a broad range of water content and compaction effort. The soil has minimum shrinkage potential and adequate strength to support the load of waste overburden. These properties discussed would fall under the purview of geotechnical engineering. But the evaluation of soil suitability is not complete without understanding its chemical reactivity. In this study, cation exchange capacity (CEC) of soil is used as an indicator of chemical reactivity. It is desirable that the pollutants released from the waste disposal site should be effectively attenuated by the liners. This means that the soil should have high chemical reactivity. A soil with high CEC indicates high reactivity and hence high attenuation capacity of pollutants.

Bioremediation of oil spills:

The case history is discussed in U. S. Congress, Office of Technology Assessment, Bioremediation for Marine Oil Spills report. It essentially deals with a marine oil spill that has occurred on the beaches of Alaska, USA, in late 80s. The reason was due to the grounding of a ship on the shores. Office of Technology Assessment (OTA), USA, felt the need of technologies to fight such calamities. A comprehensive review of the methods for oil spill clean up was conducted to develop an environmental friendly solution. One of the effective solutions that came up was bioremediation in which specific species of microorganisms were used to degrade oil. This is a slow natural process and hence the major focus was on accelerating and improving the efficiency of this natural process. Even though, some research has been initiated, it was found that there is a dearth of data and hence the advantage of bioremediation over other methods of oil spill clean up is yet to be ascertained. It has been opined that in case of emergency situation, mechanical process such as using dispersants and in-situ burning may still be appropriate.

Protecting environment from harmful effects of mine waste using cover system

O’Kane and Wels (2003) have discussed the performance based design of covers for mine wastes dumped on ground. The objective of the cover system is to control harmful contaminant release from the waste dumps, chemical stabilization of acid forming mine waste, dust and erosion control and provide growth medium for sustainable vegetation cover. The proposed methodology of cover design links predicted performance of cover system to the groundwater and surface water impacts. This method is impact oriented performance criteria. In this method, a conceptual cover is selected first based on the type of waste, size and geometry of the waste disposal, climate etc. A detailed cover design analysis is performed that correlates cover design parameters (for example cover thickness) to cover performance (net percolation). Third step links cover design parameters to environmental impact assessment (groundwater quality). Fourth step is to assess the risk based on the result from third step and the regulatory law. If unacceptable, then cover design is modified. If acceptable then field trial with performance monitoring is suggested. The feedback loop between impact assessment and cover design is crucial for developing efficient cover system without being overly conservative.

Value addition of waste products: Geopolymers from fly ash

Andini et al. (2008) have discussed about the value addition of fly ash by converting it to a product called geopolymers. Davidovits first introduced the term geopolymers for a new class of three dimensional alumino-silicate materials (Davidovits 1989). Geopolymers are alkali-activated alumino-silicate binders and its synthesis takes place by polycondensation from a variety of raw materials such as metakaolin, coal fly ash etc. Polycondenstation reaction was carried out by mixing fly ash with alkali metal silicate solution and then curing at different temperature and time. Amorphous geopolymers are obtained at condensation temperature ranging from 20 to 90 °C. The geopolymers has excellent mechanical properties, thermal stability, acid resistance and are durable. It has got a wide application in ceramics, cements, hazardous waste stabilization, fire resistant materials etc. Environmentally sound recycling of fly ash into geopolymers by hydro-thermal treatment is an excellent example of value addition to the waste material.

References

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Model Questions

1) Explain the importance and scope of geoenvironmental engineering.
2) With examples, discuss the multiphase behavior of soil.
3) Why soil becomes important in geoenvironmental engineering?
4) Discuss the multidisciplinary nature of geoenvironmental engineering.