The hidden treasures of geotechnics

Geotechnical engineering is often overlooked and oversimplified, but it continues to change the world, says Professor Marc Ballouz, of ISSMGE…

Geotechnical engineering concerns the relationship between humans and the Earth. It is the science that explains the mechanics of soils and rocks, their behaviour in nature and interactions with man-made features.

In early times the practice of geotechnical engineering was applied by trial and error, observational experience and empirical experimentation. Pyramids, temples and canals were among the first large-scale geotechnical projects with major loads and challenges. Problems such as the leaning of the famous tower of Pisa prompted scientists to start taking a more scientific-based approach to examining the subsurface. From 1717 until 1925, scientists such as Gautier, Coulomb, Darcy, Rankine, Boussinesq, Mohr, Reynold and Atterberg were authors of fundamental theories on soil pressures, soil mechanics, and water flow through soil. These theories are documented in geotechnical textbooks and are still taught in universities today. Karl von Terzaghi is considered to be the father of modern geotechnics, since his famous book *Erdbaumechanik* was published in 1925. In 1936, with his fellow colleagues, he founded the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), and became its first president.

What is geotechnical engineering?

Geotechnical engineering is often oversimplified, particularly by engineers from other fields, for reasons that are unclear. Is this due to the discipline's relatively young age? Is it still vague to outsiders? Or is it because its achievements are hidden treasures? Indeed, most of what geotechnical engineers do cannot be seen by the naked eye – their work is carried out either underground or below water. Maybe because it is such a vast field, with such complexity, simplifying it becomes a necessity; similar to saying "I want to be an astronaut to fly to another planet!".

Simply because geotechnical engineers deal with 'dirt' (this word is often misused to indicate soil) doesn't mean the task is simple; in fact quite the opposite, as soils can vary from having the consistency of mayonnaise to diamonds – the hardest soil material on Earth. The material a geotechnical engineer deals with is so variable in grain size, cementation, strength and behaviour, that it renders his/her task so much more difficult compared to other engineering tasks.

Geotechnical engineers use fundamental principles of soil mechanics and rock mechanics to investigate subsurface conditions. They examine the soil and rock layers that make up the Earth in order to determine their physical and chemical properties, to evaluate and design activities such as stability of natural slopes and man-made soil deposits, earthworks with cuts and fills, shallow foundations, deep foundations, dams, embankments, retaining walls, tunnels and many other works directly interacting with the subsoil and water, both onshore and offshore. So, challenges in this profession also come from the diversity of problems to face. In fact, ISSMGE has 33 technical committees under its auspices, each representing a particular aspect/activity of geotechnical engineering.

Fundamentals

The fundamental aspects of geotechnical engineering are the basis for all geotechnical problem-solving, and probably for most civil engineering problems as well. In fact, most civil engineering projects have to start with a fundamental geotechnical step, since civil structures have to touch, interact with or be founded properly on the soil. Hence knowing the foundation soil is a must, whether the construction involves a building, bridge, tunnel, deep excavation, or any other structure. The civil engineering designer has to know the existing terrain.

By far the most common fundamental geotechnical activity is soil exploration. Such processes start by drilling into the substratum and securing soil samples. This can vary from a simple drill rig to a very sophisticated offshore operation with specialised

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The Burj Khalifa, in Dubai, is a triumph of geotechnical engineering

vessels. Soil samples are retrieved and transported to the laboratory for testing and analysis.

Characterisation from testing the soil directly in place, also known as in situ testing, is very important, especially when combined with laboratory testing. In situ tests used today include common standard penetration testing (SPT), cone penetration testing (CPT), flat dilatometer testing (DMT), pressuremeter testing (PMT), vane shear testing (VST), as well as less-common borehole shear testing and self-boring pressuremeter testing, among others.

The world of unsaturated soil is being heavily researched and is a major part of the geotechnical fundamentals. More than 90% of geotechnical and civil engineering projects are constructed on unsaturated soils. Traditionally, soils were assumed in theory to be either dry or conservatively saturated; however, nowadays geotechnical engineers are increasingly taking into consideration the partially saturated condition for short and long-term design.

Numerical methods and physical modelling are also considered geotechnical fundamentals, since they represent modern geotechnical theories and methods utilised as advanced problem-solving techniques.

Applications

As an applied science, geotechnical engineering has no limits when it comes to both design and 'on-site' applications, which range from surface earthworks to tunnelling hundreds of metres below sea level.

A typical geotechnical application project begins with the fundamentals. Commonly a review of the project needs to define the required material properties. Then follows a subsurface investigation or soil exploration, where soil samples are taken using test pits or boreholes. Geotechnical engineers will then examine the properties of the soil, involving laboratory and in situ testing, to determine the environmental impact of disturbing the soil, as well as what steps should be taken to prepare the site for construction. Investigations can include the assessment of the risk to humans, property and the environment from natural hazards such as earthquakes, landslides, sinkholes, soil liquefaction, debris flows and rock falls. The failure to carry out adequate site investigations and consider fundamental theories has often had dramatic and expensive consequences on construction projects.

Foundation engineering is the science of connecting structures to earth. These foundations should be designed to withstand man-made live loads, natural live loads (vertical and lateral such as earthquakes), as well as the dead loads or self-weight of the structure itself. Buildings, skyscrapers, bridges, wind tur-

bines and other super structures have to bear on shallow footings, mats or deep foundations such as piles or caissons. Some structures even involve a combination of these foundation types.

As a general rule, shallow foundations are less expensive and easier to build; however, they are more susceptible to settlements and failure. One of the most famous and studied cases is the Leaning Tower of Pisa. This doesn't mean that deep foundations do not fail, as the tragic recent example of the 13-storey building in Shanghai that sheared sideways off of its piles (pictured above) illustrates.

Shoring systems are another type of geotechnical application. They include bracing of deep excavations, nailing of landslides and the supporting of tunnels, to name a few. There are many different shoring methods with different techniques and subtechniques related to the individual experience of the specialty contractors executing the works. In general, the shoring system of a deep excavation should include vertical elements such as soldier piles, or diaphragm wall and lateral elements such as braces or ground anchorage. One recent shoring failure was in Dubai, where a diaphragm wall gave away under water pressure and the entire site was flooded in just four minutes.

Offshore geotechnical works are even more impressive and challenging than onshore ones. The scale is larger, and the loading patterns are different and more intense, not to mention the difficulty of collecting reliable soil data from the soil layers under the ocean.

The failures highlighted so far are simply cited to underline the importance of geotechnical engineering design, construction and supervision. Success stories are numerous of course, and wonderful geotechnical achievements are made on a daily basis. Most of these achievements are hidden, but are nevertheless crucial; whether they were temporary in nature, such as bracing a deep excavation to construct a high rise tower like Burj Khalifah, or embedded, such as the complex foundation system of Rio-Antirrio bridge.

Impact on society

The built environment where we live serves as a dynamic interface through which human society and the ecosystem interact and influence each other. Understanding this interdependence is key to understanding the impact of geotechnical engineering on society, and how it has throughout history made changes to the way we live and even think. Projects like the Aswan Dam, Golden Gate Bridge, stabilising the cliffs of la Pointe du Hoc, and underpinning Winchester Cathedral, have surely affected our past, present and future societies.

On a parallel note, there is a growing consensus that delivering a sustainable built environment starts with incorporating considerations relating to sustainability at the planning and design stages of a project. Geotechnical engineering is the most resource-intensive of all the civil engineering disciplines and can significantly influence the sustainability of infrastructure development because of its early position in the construction process.

Of course, the impact can be negative too – being part of the over-construction around cities, and the reduction of green surface on this planet for example. Again, however, this is a global socioeconomic problem not related to what geotechnical engineers are doing, which is a reaction to public needs.

Engineering: at the foundation of European research and innovation

According to the European Commission, engineering encompasses one of the largest sectors of industry in the EU. Mechanical engineering alone, for example, provides employment for 3.3 million people, through over 160,000 enterprises, many of which are representatives of the SME sector.[1] Research to support the considerable diversity of engineering requirements across the region is supported by various channels of Commission funding.

As European businesses are expected to increase research and development spending in spite of ongoing national economic issues, the opportunities for public and private sector partnerships are also likely to be expanded – giving multidisciplinary partnerships across engineering sectors the chance to thrive.

However, the scope is far greater than the economy. For example, the key elements of foundation engineering for disaster preparedness are developed by the Commission through its Joint Research Centre (JRC). Disaster resilience, and in particular prevention and preparedness measures, are increasingly high priorities on the global political agenda and the JRC is very active in working with the European Commission's Monitoring and Information Centre, and with national partners, on technologies for crisis analysis, remote sensing data, natural hazard modelling and analysis for vulnerability assessments.[2]

In December, European Commissioner for Research, Innovation and Science Máire Geoghegan-Quinn hosted a meeting of senior international officials with the aim of advancing international scientific collaboration on disaster anticipation and resilience. One key focus area is to improve infrastructures, since most human casualties following earthquakes are due to the collapse of inadequate constructions. Assessing the vulnerability of buildings and civil infrastructures is vital in developing greater resistance to earthquakes, explosions and other accidents.

[1] http://ec.europa.eu/enterprise/sectors/mechanical/index_en.htm

[2] http://europa.eu/rapid/press-release_MEMO-12-954_en.htm

Geotechnical and geo-environmental engineering are also involved in evaluating the impact of projects on society. This is particularly critical in developing countries, where resources are scarce and every dollar spent should aim to maximise its impact on the well-being of this society. The knowledge gained from impact evaluation studies would provide critical input to the appropriate design of future projects.

Advances and research

Continuous R&D efforts are under way at the academic level, but also in large companies and institutions around the world. In design, finite element modelling, centrifuge testing, and analytical mathematical solutions are being explored with new discoveries on a daily basis.

In numerical modelling, advances have produced 3D finite element capabilities, solving problems such as complex subsidence due to tunnelling activities. Non-destructive testing techniques, similar to those utilised by NASA to evaluate the integrity of the shuttle components, were standardised in the late 1990s and are being utilised regularly to test the integrity of deep foundations for quality control. Geotechnical testing facilities in universities around the world have reached advanced levels compared to other sciences, such as a centrifuge that is capable of accelerating a 1.8 tons payload to a maximum of 200g in 14 minutes.

Remote sensing technology has also been implemented in geotechnical engineering, allowing engineers to continuously monitor and evaluate their work on critical projects, particularly when subjected to extreme loading conditions, during construction and afterwards during service.

Energy geotechnics is a hot topic nowadays. Imagine, for example, the design of deep foundations equipped with tubular conduits and used as a huge heat exchanger, with the deep soil layers to control the temperature of a building above; or the special needs for wind turbine foundations to be installed quickly offshore, capable of withstanding hurricane powers.

Research and achievements in geotechnical contracting are equally impressive, involving a cycle of giving and gaining knowledge throughout history. Projects such as the Seikan Tunnel, Boston Big Dig, Petronas towers, Manche Chunnel and Lake Pontchartrain Causeway have involved highly skilled geotechnical design and contracting teams, and have had a tremendous impact on society.

In conclusion, as a geotechnical engineer, ask not what this world can do for you – but what you can do for this world.

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