What should geotechnical professionals be able to do?

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ABSTRACT: Geotechnical professionals (geotechnical engineers and engineering geologists) should have skills that enable them to deliver designs of groundworks using information from ground investigations and client requirements, often in collaboration with structural engineers and other construction professionals. To do so they need core skills that can be assessed in terms of the tasks that they can *do* competently. This paper presents the author's perspective on the core skills required of geotechnical professionals and indicates at what stage of their education and training these skills should be acquired.

1 INTRODUCTION

1.1 *Testing skills*

People acquire skills and become competent through education, training and experience and this is a whole-of-life process; we are never too old to learn. At any stage skills can only be assessed by asking what an individual can to do competently and then testing whether or not they can. Any other criterion such as "know" or "understand" can only be assessed by a "doing" test.

1.2 *Acquisition of skills*

Acquisition of skills starts at a young age when children learn to read, write and add up and normally ends with death. The core skills of engineers are acquired by education at school and at university and by training at work.

1.3 *Geotechnical professionals*

Most geotechnical professionals acquire some core skills during undergraduate courses in civil engineering or geology but in both cases geotechnical engineering or engineering geology are only small parts of the whole course. Many acquire further skills through a post-graduate taught course and a few develop specialist skills and deep insights through research. There are different routes along which geotechnical professionals progress and acquire skills and there are mile-stones throughout a life-time of education and training; it is not a case of "one-size-fits all".

1.4 *Computer and hand calculations*

Most ground engineering professionals have access to routine computer analyses for foundations, slopes, retaining walls and other geotechnical structures and they should be able to apply these correctly. But, more importantly, they should be able to analyse simple cases by hand. In what follows the requirements are ability to do the tasks by developing analyses from first principles and performing approximate calculations by hand.

1.5 *Constraints and expectations*

There are constrains on what is possible and there are expectations of employers and society. Universities are constrained by the ability of entrants; this is an issue for schools. They are constrained by the time available and the allocation of time to topics within a course; this is mostly an issue for the university staff. Graduates expect that their qualification will give them earning power and employers expect graduates to be able to contribute to the company. Often employer groups, (in UK it is the Institution of Civil Engineers) validate university courses and so constrain what is in the syllabus but at the same time they are declaring what they expect of graduates.

1.6 *What and how?*

Within the context of this conference there are two basic and distinctly different issues. One is to describe the core skills that geotechnical professionals should have – what they all should be able to do.

This is the topic of this paper and it is for discussion. The other is to consider how people acquire these skills through education, training and experience. This is a matter of educational psychology and will be considered by other authors.

2 PROGRESSION AND ROUTES

Table 1 illustrates routes followed by geotechnical professionals as they progress through education and training.

The rows represent progression from school, through university and the first 5 years of post-graduate work which would probably include a post-graduate degree. The columns represent basic job descriptions. The task is to consider how specific skills should fit into the relevant cells – what should civil engineers, geologists, geotechnical engineers and engineering geologists be able to do at various stages of their education and training.

There are no, or very few, undergraduate courses in geotechnical engineering or engineering geology. Post-graduate courses in civil engineering and geology are too broad for engineers or geologists to acquire specialist geotechnical skills. Relevant research should lead to specialization beyond the core skills.

Those with an undergraduate degree in civil engineering and 5 years experience should have some core skills in geotechnical engineering but graduates with an undergraduate degree in geology would normally complete a post-graduate course in engineering geology to acquire core skills in engineering geology.

In practice, engineering geologists focus on ground investigations and creating geological models while geotechnical engineers focus on designing ground works and geotechnical structures from geotechnical models using tools from soil and rock mechanics.

3 HOW TO DESCRIBE SKILLS

In describing core skills there is a conflict between detail and scope. For example descriptions of several separate skills could include:

- find solutions to simple mathematical problems;
- create a geological model;
- determine the strength and stiffness of soil samples from laboratory tests;
- calculate bearing capacity and settlement of a simple foundation;
- design a foundation to support complex and variable loadings.

A competent ground engineer should be able to design a foundation to support complex and variable loadings but this requires skills in all the others. A full list of what ground engineers should be able to do might include all these but the list would then be very long. But a list that contained only items such as “design a foundation to support complex and variable loads” would be short but less helpful. There has to be a balance.

An issue that often arises is whether ground professionals should be able to analyse simple structures from first principles or is it sufficient that they can correctly apply published solutions, codes and standards and perform routine computer-based analyses. For example should a ground engineer be able to derive the bearing capacity factors N_c, N_q, and N_γ? Without deriving these, or at least seeing them derived, users have little appreciation of the assumptions required in the derivations and the limitations of the factors themselves.

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Table 1 Progression of geotechnical professionals

<table>
<tr><th></th><th>Civil engineer</th><th>Geotechnical engineer</th><th>Engineering geologist</th><th>Geologist</th></tr>
<tr><td>School</td><td>Science and maths</td><td colspan="2" rowspan="2">N/A</td><td>Science</td></tr>
<tr><td>UG degree</td><td rowspan="2">General civil engineering</td><td>General geology</td></tr>
<tr><td>5 years</td><td rowspan="2">Ground engineering practice</td><td rowspan="2">Ground investigation practice</td><td rowspan="2">Other topic in geology</td></tr>
<tr><td>PG Degree</td><td>Other topic in civil engineering</td></tr>
<tr><td>Research</td><td>Specialisation</td><td>Specialisation</td><td>Specialisation</td><td>Specialisation</td></tr>
</table>

Table 2 Core skills of geotechnical professionals

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1 Basic skills

1.1 Write an essay

1.2 Solve problems using arithmetic, algebra, trigonometry and simple calculus

1.3 Write a technical report

1.4 Create spreadsheet calculations

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2 Material behaviour and properties

2.1 Measure ϕ' for dry sand from slope angles and measure undrained strength of clay cylinders

2.2 Relate s_u of clay to liquidity index

2.3 Do sandcastle experiments on sand and relate pore pressure to water content

2.4 Do CU and CD triaxial tests and determine strengths and stiffnesses

2.5 Do 1D consolidation test; determine m_v and c_v and yield stress

2.6 Perform and validate numerical analyses

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3 Investigations and modelling

3.1 Describe soil and rock in engineering terms

3.2 Design and manage a ground investigation

3.3 Create *geological* model including history

3.4 Create *geotechnical* model: = geological model + parameters for analysis

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4 Groundwater

4.1 Draw simple flownet and calculate flow rate

4.2 Determine u at any point in a flownet

4.3 Determine permeability k.

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5 Slopes and walls

5.1 Calculate limiting undrained slope height and limiting drained slope angle

5.2 Calculate slope angles with seepage

5.3 Analyse slope stability in jointed rock

5.4 Calculate limiting active and passive forces on a wall

5.5 Design simple gravity walls

5.6 Design cantilever and propped walls

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6 Foundations

6.1 Calculate bearing capacity and settlement of simple shallow foundations

6.2 Design a foundation; part buried and variable groundwater

6.3 Design an embankment on soft ground

6.4 Determine capacity of a single pile and a simple pile group

6.5 Design piled foundations

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7 Earthworks and materials

7.1 Determine compaction curve

7.2 Design earthworks and pavements

7.3 Assess aggregate resources

Table 2 contains a relatively long list of skills some of which civil engineers, engineering geologists and geotechnical engineers might be expected to have acquired at various stages in their education and training. Some of these, such as solve mathematical problems, are basic skills while others, such as create spreadsheet calculations, require some mathematical ability as a pre-requisite. Similarly determine pore pressure in a flownet requires ability to draw a simple flownet as a prerequisite.

The topics in the list in Table 2 are restricted to geotechnical engineering of common ground structures such as slopes, walls and foundations and include earthworks and aggregate resources. The list does not include specialist ground engineering topics such as tunnels, ground improvement and reinforced soils. Also the topics in Table 2 exclude specific non-engineering topics such as hydrogeology, groundwater resources, contaminant transport and storage and so on.

Most of what is discussed in this paper is applicable to saturated (or dry) soils but in many cases soils in practice are unsaturated. There is currently no simple and realistic theory for strength and stiffness of unsaturated soil similar to the effective stress theory for saturated soil. Clearly ground professionals should know that soils may be unsaturated but, in the absence of a simple theory, detailed analyses for unsaturated soils may be beyond the core skills of most geotechnical engineers and engineering geologists.

Table 2 is my list and it is for debate. Others may wish to add to it, remove items and generally make modifications. But the real task is to insert the various items from Table 2, or its revisions, into the cells in Table 1. Before I make my own suggestions I need to discuss the items in Table 2.

4 CORE SKILLS

The ability to write an essay and solve problems using simple mathematics are basic skills and should be taught at school. (It is not clear what universities and employers should do if school leavers and graduates do not have these skills but that is a separate issue.) Graduate civil engineers and geologists should be able to write technical reports which reach logical conclusions and create spreadsheet calculations and employers of engineers and geologists would expect that they can.

4.1 *Material behaviour and properties*

Skills in assessing the behaviour and properties of soils require distinctions between total and effective stress and between drained and undrained loading together with basic definitions of strength, stiffness, friction, cohesion and so on.

Simple measurements of friction angles of sand and undrained strengths of clay do not require sophisticated equipment. Slope angles before and after failure illustrate peak, critical state and residual strengths; liquidity index requires knowledge of the Atterberg limits.

Determination of pore pressures in sandcastles is a test of fundamental soil mechanics. The analyses require construction of Mohr circles of total and effective stress to show how negative pore pressure, coupled with friction, develops unconfined compressive strength. The tests and their analyses also illustrate relationships between water content, suction and grading.

Geotechnical engineers and engineering geologists who specify triaxial and oedometer tests should be able to do them and analyse the results to obtain design parameters. Doing these tests means doing the tests entirely themselves, not watching someone else do them.

Numerical analyses, most often using finite elements, are now more or less routine in ground engineering. Analyses of even simple problems often use numerical models that are more sophisticated than purely elastic and Mohr-Coulomb. Most importantly analyses should be validated by comparison with hand calculations and laboratory tests, by close examination of stress and strain paths in selected locations and other means. Validation of numerical analyses requires common sense, deep understanding of fundamental soil mechanics and ground behaviour but not necessarily high-level mathematics.

4.2 *Investigations and modelling*

Ground information comes from ground investigations including desk studies, field work and laboratory testing.

Objective descriptions of soils and rocks in exposures or in samples require a common language and a common framework. This requires ability to sketch a grading curve from a hand sample, ability to describe the consequences of manipulating samples to assess consistency and weathering and ability to describe discontinuities. All geotechnical professionals should be able to describe soils and rocks using engineering terminology.

A *geological* model consists of a series of 3D block diagrams each showing a significant moment in the past as materials are deposited, weathered, faulted, folded and eroded: An employer would expect a geology graduate to be able to create a geological model.

A *geotechnical* model consists of a 3D block diagram of the site showing locations of materials with the same engineering properties of strength, stiffness and permeability. The geotechnical model is essentially a simplified and idealized version of the geological model with engineering parameters added. It is the basis for analyses of the proposed works. Creation of a geotechnical model requires knowledge and understanding of geological processes and material behaviour and the relationships between soil and rock description and behaviour.

4.3 *Groundwater*

Groundwater influences ground behaviour and geotechnical analyses through pore pressures which control effective stress and rates of flow which determine leakage and requirements for pumping excavations and rates of consolidation.

How pore pressure and drainage influence effective stress, strength and stiffness are included in Section 2 Material Behaviour and Properties. For steady state (drained) conditions the geometry of a flownet governs distributions of pore pressure and, together with coefficient of permeability, rates of flow.

Other aspects of groundwater such as water resources and contamination transport are outside the scope of routine ground engineering.

4.4 *Slopes and walls*

Analyses of stability of simple soil and rock slopes and walls for drained and undrained conditions in soils using hand calculations for simple cases requires knowledge of material behaviour and properties and techniques of stability analyses. The analyses become more complicated for cases that do not have simple geometry and particularly when there is seepage of groundwater.

Design of gravity walls is relatively simple and requires basic skills in determining earth pressures and overall stability. By contrast design of cantilever and propped walls is much more complicated and often requires assessment of movement and loads in the wall and props. There are several competing methods and detailed design of large walls often requires specialist skills.

4.5 *Foundations*

Calculation of bearing capacity and settlement of simple shallow foundations for drained and undrained loading and during consolidation from standard bearing capacity factors and published elastic and consolidation solutions is relatively straightforward. The problem becomes more taxing when the foundation is part buried and lightweight (as in an underground car park), when the applied loads are variable and eccentric and when groundwater conditions vary.

The strength of compacted fill in an embankment on soft ground is usually significantly greater than the strength of the soft ground and the issue is really

Table 3 Progression of ground professionals

<table>
<tr><th></th><th>Civil Engineer</th><th>Geotechnical engineer</th><th>Engineering geologist</th><th>Geologist</th></tr>
<tr><td>School</td><td>1.1, 1.2, 1.4</td><td colspan="2" rowspan="2"></td><td>1.1, 1.2, 1.4</td></tr>
<tr><td>UG Course</td><td rowspan="2">1.3
2.1, 2.2, 2.3
3.1
4.1, 4.2
5.1, 5.4
6.1, 6.4
7.1</td><td>1.3
3.1, 3.3
4.1
7.3</td></tr>
<tr><td>5 years</td><td rowspan="2">2.4, 2.5, 2.6
3.4
4.3
5.2, 5.3, 5.5, 5.6
6.2, 6.3, 6.5
7.2</td><td rowspan="2">2.4, 2.5
3.2
4.3
5.1, 5.3
6.1, 6.4
7.1</td><td rowspan="2"></td></tr>
<tr><td>PG Course</td><td></td></tr>
</table>

one of bearing capacity and magnitude and duration of settlement. Design of embankments on soft ground may require staged loading, modified drainage and ground improvement.

Calculation of the capacity of a single pile and a simple pile group using published solutions is relatively straightforward. Design of large piled foundations is much more complicated. This requires, among other things, selection of pile type, analyses for variable and eccentric loadings, calculations of movement and the influences of pile caps. As with the case of large walls, detailed design of large pile groups often requires specialist skills.

4.6 *Earthworks and materials*

A substantial part of ground engineering involves use of soil and rock as a construction material compacted in embankments, fills and pavements and processed into concrete aggregate.

An essential core skill is determination and assessment of compaction and of suitability of material as fill. Design of earthworks and pavements requires, in addition, specification and control of field compaction.

Assessment of aggregates is essentially an issue of chemistry and mineralogy rather than mechanics and engineering.

5 WHAT SHOULD GEOTECHNICAL PROFESSIONALS BE ABLE TO DO?

In Table 3 I have placed the core skills from Table 2 into the career stages and route diagram in Table 1. This is my personal view and it is open to discussion.

Entry to undergraduate courses in civil engineering and geology should require basic numerical and literary skills. A geotechnical engineer with a first degree in civil engineering and 5 years post-graduate experience including a post-graduate degree should be able to do nearly everything listed in Table 2. Without a post-graduate degree a civil engineer should have only the basic geotechnical skills listed but would have developed other skills in structures, hydraulics and management.

The skills of those with a first degree in geology are often limited by lack of mathematics and mechanics including analyses of stress and strain and application of strength and stiffness. With a post-graduate degree, an engineering geologist should be able to do simple analyses of slopes, earth pressures and foundations using standard solutions.

6 EXAMPLE: CAISSON FOUNDATION

The apparently simple example of a caisson foundation in Figure 1 in fact contains a number of issues requiring careful consideration. The walls of the hollow caisson are 0.2m thick. The river is tidal but there are artesian pressures and at a depth of 8m below the river bed, pore pressures remain constant with a head of 12m at all states of the tide.

In one case the soils are 50% silt and 50% clay, the plasticity index is 30 and the liquidity index is 0.1. In another case the soils are rounded medium sand and the relative density is 0.9. In both cases the

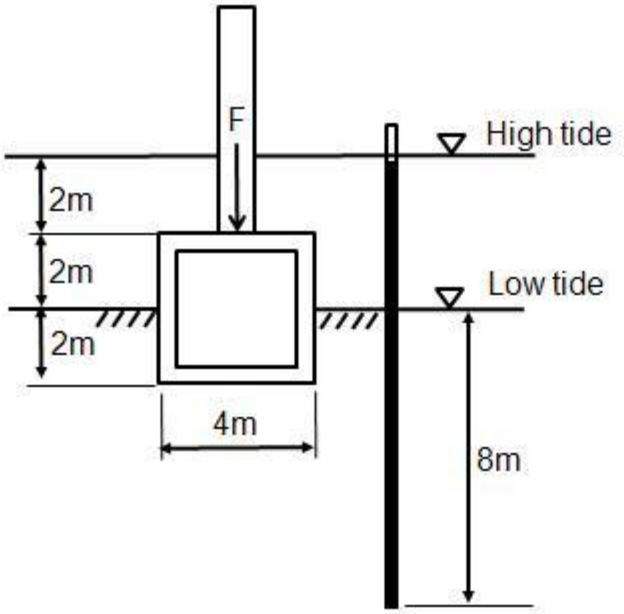

Figure 1 Simple caisson foundation

unit weight is 20kN/m^3. From these data a ground professional should be able to make reasonable estimates of strength and stiffness for preliminary design.

The task is to determine the applied load F to limit the settlement to 10mm and to determine the difference between this and the load to cause failure. A competent engineer would consider the case during construction before the load F is applied and consider the consequences of rising and falling tide.

The caisson is relatively light weight, it is partly buried and groundwater and pore water conditions vary. It is not easy to apply standard text-book bearing capacity equations. Without the applied loads the caisson floats. For the sand the soil would be drained at all times so at low tide there is upward seepage. For the silty clay the mean settlement is greatest at the end of consolidation but during a tidal cycle the soil would be undrained.

Correct analyses of the caisson in Figure 1 would require many of the skills in Table 1. Similar examples can be created for analyses of slopes and walls in which geometry and changing water conditions require careful consideration.

7 SUMMARY

In this paper I have listed a set of core tasks that geotechnical professionals - geotechnical engineers and engineering geologists - should be able to do and I have indicated at which stage of their education and training they should acquire these skills.

Although, in practice, analyses of foundations, slopes and walls are done using routine computer programs, ground professionals should be able to do these analyses from first principles and obtain approximate solutions by hand calculation.

Some tasks, such as design of large walls and large piled foundations, require specialist skills and are beyond what could be expected of a competent geotechnical engineer and are certainly beyond the skills of an engineering geologist. Some activities, such as groundwater resources and contaminant transport, while important, are outside the scope of routine ground engineering.

Before there are considerations of when and how geotechnical professionals acquire skills at school, at university and in practice by lectures, exercises, simulations and so on it will be helpful to agree what they should be able to do. In this paper I have made proposals that are intended to form the basis for discussion.