GEOTECHNICAL COURSE DATES:

Rock Description

29th March 2013

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GEOTECHNICAL COURSE DATES:

Geotechnical Foundation Design - 126th April 2013

Soil Description

1st Feb' 2013

7th March 2013

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H&S COURSE DATES:

Avoiding Danger from Underground Services

8th Feb' 2013 & 8th March 2013

Safe Supervision of Geotechnical Sites:

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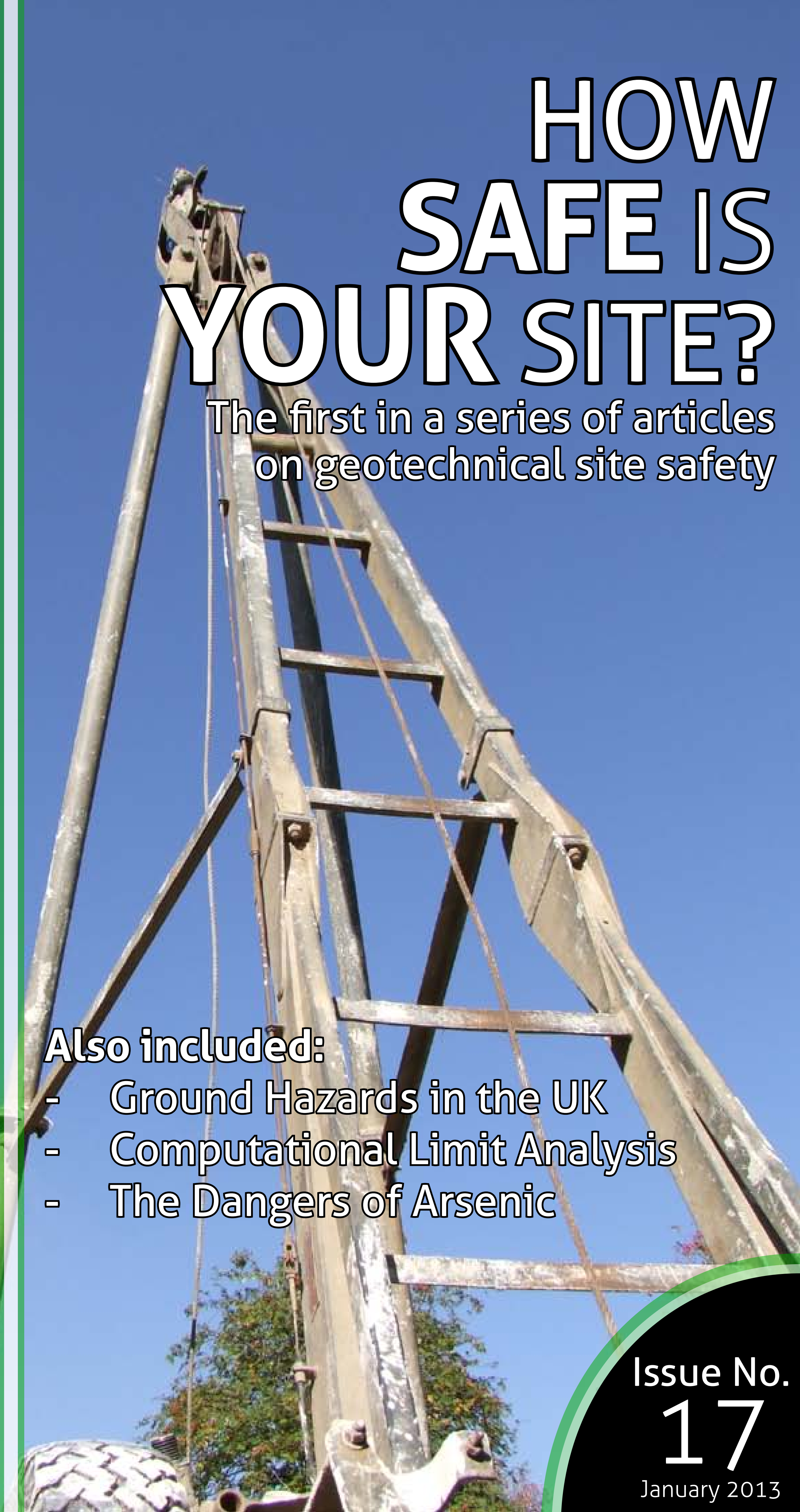


HOW SAFE IS YOUR SITE?

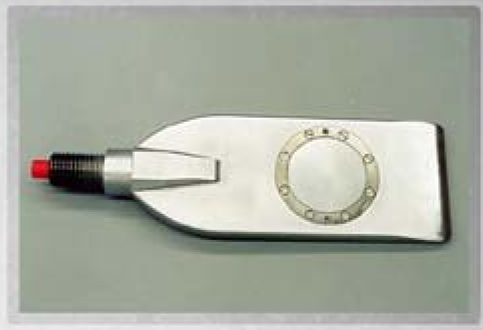
The first in a series of articles on geotechnical site safety

Also included:

- Ground Hazards in the UK
- Computational Limit Analysis
- The Dangers of Arsenic

Issue No. 17
January 2013

Contents



Welcome

Happy New Year!

Welcome to the first issue of **theGeotechnica of 2013**, the 17th edition of the industry's leading exclusively online concept emagazine. With the new year in full swing, we have an exciting collection of excellent articles for your reading pleasure.

This month we have a highly valuable contribution from the esteemed Dr Jackie Skipper of the Geotechnical Consulting Group. Jackie's article discusses the ground hazards that many companies encounter working in the United Kingdom. In addition, Jackie discusses how we can forsee these issues and avoid them in the future. Furthermore, Jackie discusses some highly useful, but often forgotten pieces of technology such as Google Earth that can aid geotechnical works greatly in the planning stages.

Jackie's article is not the only must-read section of this month's magazine. Our cover article is the first in the series of articles from the Equipe Group that will examine and discuss the safety issues that all geotechnical and drilling crews encounter when working on site. The aim of this series is to increase awareness of health and safety best practice that must be adhered to in order to meet health and safety legislation, as well as saving on-site workers time in the long run. This month's offering focuses on the amount of space needed for a cable percussion rig to operate safely, as well as advice on how to ensure accidents and obstructions are avoided when transporting the rig to site.

On page 19 we have an intriguing article from Dr Tom Pritchard of LimitState Ltd. Dr Pritchard will discuss computational limit analysis, a tool that is fast becoming essential to all practicing geotechnical engineers. Computational limit analysis looks set to replace older, more time consuming methods of determining the critical failure mechanism of most geotechnical works.

Finally, we have another excellent contribution from Hazel Davidson of Derwentside Environmental Testing Services. In this month's edition of **theGeotechnica**, Hazel examines the properties, uses, toxicity and analysis of arsenic.

We also have new entries into the Directory and Jobs sections, with positions available at Geotechnical Engineering as well as Gardline Geosciences.

As with every new edition of the magazine, the Editorial Team here at **theGeotechnica** will be on the lookout for even more new, original and interesting content from all corners of the sector, and would actively encourage all readers to come forward with even the slightest bit of appropriate and relevant content - whether it be a small news item or a detailed case study of works recently completed or being undertaken. If this content is media rich and interactive, then all the better. We are looking to increase the already large readership of the magazine through better social media integration and promotion, as well as improving content month on month.

Once again, for any content that is submitted we will provide free advertising space, proportionate to the quality of content provided, for that single edition of the magazine. From then on, if you have submitted content, you will receive a discount on all further advertisements placed within **theGeotechnica**.

We hope you enjoy this month's edition of the magazine and are inspired to contribute your own content for the coming editions of theGeotechnica.

Editorial Team,
theGeotechnica

GROUND HAZARDS IN THE UK

AND HOW TO FORSEE THEM

Writing for ***theGeotechnica*** *for the first time is the* [Geotechnical Consulting Group](#)*'s esteemed Senior Geologist, Dr Jackie Skipper. In this in-depth article Jackie discusses the many ground hazards that face geotechnical companies in the UK and what can be done to forsee them. The article itself is based around Dr Skipper's chapter entry in ICE's Manual of Engineering Geology that can be found* [here](#).

Geotechnical engineering is one of the most challenging of engineering specialities. Why? Because the ground is much more diverse and variable than any man-made material. Considering how key the ground properties are in the success of ground engineering projects (it sometimes keeps structures upright for many hundreds of years - isn't that amazing?), it is, in truth, the worst understood of the materials we work with. On site we commonly have a far more representative sampling and testing regime (and a much better understanding) of concrete and grout mixes than of the ground of our project - the ultimate material with, in and on which we work. Often the only time we understand the ground very well is when things have gone wrong and we have ended up involved ina claim for unexpected ground conditions.

In my work I often encounter people ending up as victims of their ground conditions rather than understanding and mastering them. Sometimes this is because humans don't see that the ground can constitute a hazard when we mess with it. True – the Earth isn't hazardous in its own right - it does what it does and gravity, water, heat (or lack of it), plants

"But humans often make the ground more hazardous by where we chose to live and work, by how we treat it."

and animals and the sun do the rest. But humans often make the ground more hazardous by where we chose to live and work, by how we treat it. Landslips, for example, may appear to be hazardous, but they don't actually represent a risk until humans decide they like the view from the cliffs overlooking the sea, and make their home there (there are huge landslips on Mars but so far they haven't constituted a hazard to humans).

"The success of the human species has pushed us to develop, live and work in more challenging areas..."

The success of the human species has pushed us to develop, live and work in more challenging areas (e.g. steep hillsides, bogs etc.), for good economic, aesthetic or social reasons. Humans also have extraordinarily short memories of relatively recent hazardous ground events and we often emotionally weight an advantage (e.g. a lovely view, familiarity, investment potential) over a disadvantage (cliff recession, landslips, flooding). Nevertheless, modern advances in civil engineering mean there are only a few environments that we cannot engineer if enough money, a good understanding of the ground and a suitable design are involved. So ground hazards, ultimately, only become risks if they are unforeseen and unmitigated – and it requires a degree of training to recognise such things.

Why Bother?

An engineer in Australia once asked, after one of my lectures, why don't we just drill a couple of boreholes, test what comes up and base the design on that? My response was to use an analogy: if the ground is represented by a wedding cake at the bottom of a black plastic bag, and the borehole is your hand reaching into the black plastic bag, to grab a 'representative sample', you may end up basing your design on a rosebud. Boreholes represent a miniscule fraction of the ground. Geological boundaries usually don't consist of straight lines between two boreholes, the ground between being exactly the same as that recovered in the boreholes.

The second reason for bothering is because many companies try to cut costs by having a 'cheap' site investigation of the 'couple of boreholes' type, but this is usually a process in which valuable data can be missed. In fact, saving money with a 'cheap' site investigation is practically the biggest waste of money in the construction industry over the long term - hence the inverted commas. However, despite improvements in standards of site investigation over the past few years there will always be economic downturns. 'Cheap' site investigations will always be sought and undertaken, but can miss out important changes

"This is not only because fewer boreholes, of a cheaper type, with fewer samples give you less data, but because 'cheaper' staff may not be so well trained..."

in the ground. This is not only because fewer boreholes, of a cheaper type, with fewer samples give you less data, but because 'cheaper' staff may not be so well trained in what they are logging: in taking samples for testing, in the testing itself.

It is important that engineers at all levels understand and are conversant in the many facets of Geotechnics. Even with a full EC7-approved site investigation and testing schedule it is possible for important information about the ground to slip through the cracks between the specification and the interpretative report, so every bit of available information needs to be made the most of.

Of course - in geotechnical engineering it is possible to compensate for less adequate SIs by adopting a conservative design - by taking fewer risks, or alternatively by taking the basic minimal information available and taking the risk that the ground will be fine. But those extremes have again been shown repeatedly (Chapman and Marcetteau, 2004) to be definitely not the smartest and most cost-effective solutions. Understanding the ground to the best of our ability, and designing with the ground in mind, makes the best economic sense.

Some ground hazards in the UK

It is not the aim of this article to exhaustively list all ground hazards, but instead to discuss them and introduce ideas by which the reader can learn more

"UK ground hazards generally can be grouped into 3 categories: Regular Geological Hazards, Seismically-related Geo-Hazards, Surface Process Hazards and Anthropogenic hazards."

about them. UK ground hazards generally can be grouped into 3 categories: Regular Geological Hazards, Seismically-related Geo-Hazards, Surface Process Hazards and Anthropogenic hazards.

Regular Geological Hazards

The most frequently encountered category in the UK includes ground types which are:

- harder,
- weaker,
- softer,
- looser,
- have more and bigger holes or caves in them,
- are more variable,
- less stable,
- more aggressive, or
- contain water or gas at higher pressures than we want them to.

Of course in an ideal engineering world all geological deposits would be laterally extensive, of uniform and predictable thickness and homogeneous in nature. Unfortunately the ground is usually variable. Maybe it's time to worth with it? While it is possible to be exceptionally lucky and find tens of metres thickness of well-behaved, unweathered, unfaulted, horizontally-bedded strata across an entire project site, it is actually not the norm.

"The reason for this is the variability of processes which contribute to the deposition of soils and rocks..."

The reason for this is the variability of processes which contribute to the deposition of soils and rocks, and which alter them afterwards.

Generally the most uniform, homogenous and laterally extensive rocks are marine sediments, which were often deposited as essentially the same type of soil or rock over hundreds of thousands of kilometres for hundreds of thousands of years or more. But even so, don't be lulled into a false sense of security. Even very thick, fully marine deposits sediments like the Oxford Clay, Carboniferous Limestone, or London Clay vary vertically in strength, texture and permeability due to changes in water depth while they were being deposited. And the nearer to the shore they were deposited, the more variable the deposits get (think of the Carboniferous Coal Measures, or marginal marine to terrestrial Mercia Mudstone Group). When we superimpose on this variability the worldwide fluctuations in sea level and the extremes of climate variation over geological time (especially the past 2-3 million years of very extreme climate), then we end up with a stack of potentially very variable geology indeed. Superimpose on those the deposition or intrusion of igneous rocks, or start to look at the processes of folding, faulting and metamorphosis, this variability cranks up yet another factor or five.

Don't panic though. Variability is still only a potential risk if it is not anticipated. It is here that a geologist can really make a difference - but just being trained to appreciate the differences between strata and how to recognise common geological processes can go a long way to being able to see a potential hazard.

Seismically-related geo hazards.

This category includes things that the earth does which we consider very unreasonable. These include proper, dramatic geohazards such as:

- volcanoes,
- earthquakes,
- debris- or mudflows resulting from volcanic activity, and
- tsunamis,

These are the sort of geohazards that even a New Zealander could not be disparaging about. In the UK we are luckily considered low risk for these hazards since we are currently a long way from tectonically active centres. (Only a geologist would say this. What I mean is: during the past 40my or so we have been in a relatively stable tectonic setting –this is considered a short period for a geologist).

"However, we do have occasional earthquakes, especially in certain areas, and (in the historical past) tsunamis due to earthquakes or underwater landslide failures."

However, we do have occasional earthquakes, especially in certain areas, and (in the historical past) tsunamis due to earthquakes or underwater landslide failures. Seismic hazards do therefore need to be considered for long-term or, sensitive projects such as tunnels, nuclear power stations and coastal projects. To discover more about this, the British Geological Survey has an abundance of very useful information, historical data and risk maps for these geohazards on their website.

"Volcanoes are even less common here - the last ones to erupt on the UK mainland were about 55-60 million years ago..."

Volcanoes are even less common here - the last ones to erupt on the UK mainland were about 55-60 million years ago - but many of our soils and rocks still contain layers of volcanic ash laid down or reworked within them. These ashy sediments frequently contain swelling clays which may cause heave or settlement, exacerbate landslips, slow down tunnelling operations and impede soil handling. If you are in any doubt, get the clay minerals analysed.

Surface process hazards include the multitude of hazards which are primarily concerned with how gravity and erosion affect the ground, and also with how water interacts with the ground near or above its surface.

"Landslips and landslides, mudslides, coastal erosion and flood risk all come into this category."

Landslips and landslides, mudslides, coastal erosion and flood risk all come into this category. Uplift (caused by the action of the earth's tectonic plates moving in relation to each other) has a lot to answer for. Topographically higher ground is (in geological terms) just waiting for gravity to act on it, to be weathered out, fall down, to be tallus for a bit until it falls further, gets washed into a river and eventually breaks down into sand to be redeposited in the sea as sediment. Again however it is important to recognise that humans love to build in high places, near the sea and everywhere in between - but that hilly areas can fall down, coastal and low lying areas often flood, and will probably do more so in the future.

"Again however it is important to recognise that humans love to build in high places, near the sea and everywhere in between..."

Anthropogenic hazards

Humans have been messing around with the ground for several thousand years, but in the last 200 years we have changed the planet more than any other species (including ourselves).. Amazing human skills have enabled us to use fossil fuels to facilitate advances in transport and industry (often leaving interesting large holes in the ground where they were taken from) and our skills in civil engineering have enabled us to master many formerly forbidding environments and locations in order to continue to do these things.

An awareness of how an area has changed over time will always repay study - often revealing a wide range of human activities, many of which may have implications for the particular project you are working on. For example, in an area of east London near where I used to live there was, from the oldest to the youngest:

- a Bronze Age trackway development (archaeology),
- a coal gas production plant (contamination and underground structures),
- Joseph Bazalgette's Northern Sewage Outfall (Victorian tunnels and obstructions), and
- past and present industry associated with the London Docks (archaeology, pollution and obstructions).

Superimposed on these layers and issues were:

- the abundance of bombs dropped in the area during 1939-1945 war (possible unexploded ordnance),
- the relatively new Dockland Light Railway and its tunnels, and
- normal everyday services.

To help steer your way through this potential minefield of man-made hazards, there are many companies who will, for a reasonable fee, provide site-specific environmental risk information and historical mapping for your site area,

"The clever bit is seeing how all these things fit together, and which will most impact on what is planned."

The clever bit is seeing how all these things fit together, and which will most impact on what is planned.

How can I tell what the ground has in store?

I am constantly delighted and amazed by what we are able to access from our PCs today – there is more information about the ground of a potential site, available faster, than ever before. Programs such as Google Earth give us aerial imagery which previously required payment, long waits or searches, and possibly special viewing equipment (although I have to say stereo pairs of aerial photos can still provide another level of information). Not only can we look up our site in seconds but in one go we can discover what volcanoes or earthquakes have occurred nearby (try ticking Gallery in the Layers folder, tick Earthquakes), elevation (don't trust these completely though, they are approximate), distances between interesting points. Using Street View within Google we can get a wonderful close-up of topography and buildings in a project area. Using the Historical Imagery facility (in the View dropdown menu) we can even see if the area has changed over the previous few years – this is useful for spotting landslips or previous developments.

"Not only can we look up our site in seconds but in one go we can discover what volcanoes or earthquakes have occurred nearby..."

Armed with Google Earth and a geological map of your site area it is possible to assemble a great deal of quality information to assist your understanding of the ground in your project area within an hour or so by looking at the:

Water

Where is the water in this area - in rivers, streams, lakes, marshes, an estuary, the sea? Does it make sense where the water is or is there poor drainage due to impermeable strata? Is the site in an obvious flood risk area (i.e. at or near sea level or the same level at which all the local rivers run?) Is there no water at all in this area? Did there used to be? Where could it have gone?

Topography

Running the cursor over the aerial view of the site and surrounding area will give you an idea of variations in topography. The next question to ask is - does the topography make sense and, if not, why is it like this? If you look at the topographic or geological map, is there an obvious reason?

Anything weird looking?

Is there anything that doesn't seem quite right, or any colours or shapes on the ground that don't make immediate sense in terms of natural or human activity? Are there any areas where buildings 'should be' but aren't? Road names ▶▶

Figure 16. Landslips near Castle Hill, Newhaven, Winter/Spring 2001.

can be very useful indicators of geological or former engineering hazards. Are there road or lane names near your site which include such words as:

- Water or watermeadow,
- Flood,
- Spring,
- Bourne,
- Swallow or Swallowhole,

(all possible flood or solution hazards)?

- Brick,
- Kiln,
- Mine or
- Quarry

(may indicate former mining or quarrying)?

- Undercliff,
- Zigzag,
- Slip,

(may indicate possible ground instability problems)?

- Cave or
- Dene

(can also indicate natural or man-made cavities).

"In Google Earth, Street View can be another useful source of information..."

In Google Earth, Street View can be another useful source of information, often picking up uneven ground surfaces, major cracks in the walls of houses, and repeatedly re-made roads in areas of ground movement or change.

If for any reason you cannot use Google Earth in your company there are an increasing number of other remote viewers which are free to use such as Yell.com and Bing Maps, both of which allow 3-D inspection of built sites in UK cities.

Geological Maps

Geological maps are, to the average engineer, confusing. It's not surprising. Even geologists of many years standing can be initially bemused when studying a new map. They have bizarre colour schemes and funny symbols. They use unfamiliar words and names. But they also contain vast amounts of useful information if you have a little patience. If you want help, ask a friendly geologist or put 'How to read geological maps' into a search engine. A note of caution however. Engineers often consider geological maps to be like technical drawings. They aren't. They are produced by clever, experienced geologists who do a lot of field work, incorporate as many good quality boreholes as possible,

"Even using state-of-the art geophysics, they don't have x-ray vision."

and extrapolate their findings. Even using state-of-the art geophysics, they don't have x-ray vision. Geological maps, while a very good best guess of what the ground consists of, are approximate and should always be used with that in mind.

Another important point to mention here is that just because a geological formation is called e.g. Kimmeridge Clay (or Lias Clay, or Gault Clay) doesn't mean that it is only clay. (A very intelligent engineering colleague, who had undertaken research on the Lias Clay, was horrified, on visiting Lyme Regis, to discover that it had lots of hard limestone layers in it). Likewise, Formation names with 'Sand' at the end (Lower Greensand, Arden Sandstone) rarely consist entirely of sand

"Soils and rocks of any age or name usually contain naturally occurring harder layers, or weaker layers, or indeed more clayey or sandy layers..."

or sandstone. Soils and rocks of any age or name usually contain naturally occurring harder layers, or weaker layers, or indeed more clayey or sandy layers – be prepared and read the geological map to the best of your ability. Again the BGS has very useful tools on their website such as the Lexicon of Named Rock Units (don't be deterred from looking up soils on this site – 'rock' equals rock or soil in this instance). The BGS Onshore Borehole Historic Database is, now mostly free, too, and in combination with the Lexicon it will often quickly tell you far more than you ever wanted to know about the strata in the area of your project, and this information will act as the basis for a refined ground model based on a well-designed site investigation.

Why try to be clever?

I would say that an infuriating accusation that is occasionally laid at those who undertake research into engineering geology and geotechnics is of

"I have long ago abandoned the word 'interesting' when involved in a project..."

'trying to be too clever'. I have long ago abandoned the word 'interesting' when involved in a project and frequently have to strongly defend a specification for a further site investigation against accusations that; "You are only doing this for your company records/for your own research". Quite apart from the fact that the geology I have already studied has probably provided quite enough data to keep me writing papers for the rest of my career, obtaining enough information about your site is rarely a luxury. And being interested is not a frivolity. We are intelligent people, otherwise we wouldn't be working in this industry. Use your brain! And treat others as if they had one too. Involving colleagues and site staff in understanding the ground conditions can help with the development of the ground model, the identification of potential hazards and can improve the quality of communications all round.

Conclusions

"The ground isn't naturally 'hazardous' – it is how we humans chose to interact with it that can make it so."

The ground isn't naturally 'hazardous' – it is how we humans chose to interact with it that can make it so. It is however variable and can behave in many ways we don't want it to. For this reason it is a false economy to believe we can just 'drill a few boreholes and do a few tests' to determine a geotechnical solution - in fact this can end up being very expensive and even dangerous.

Developing a well-informed, intelligent approach to a better understanding of the ground is actually the only sensible way forward. It helps enormously in planning and designing for a project, makes the best technical sense and contributes true value to engineering projects.

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UPCOMING COURSES - 2013

SOIL DESCRIPTION WORKSHOP - 1st February 2013, 7th March 2013, 31st May 2012

ROCK DESCRIPTION WORKSHOP - 29th March 2013

GEOTECHNICAL FOUNDATION DESIGN - 26th April 2013

IN SITU TESTING - 24th May 2013

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ROTARY DRILLING TRAINING

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Equipe Training are offering comprehensive Rotary Drilling Training that will take place over the course of three days. Each day will focus on a specific aspect of rotary drilling with the aim to give all attendees a high level of understanding of the skills, techniques and knowledge required to safely and effectively operate rotary drilling rigs.

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- Coring and Core Barrels
- Demonstrations

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EQUIPE GROUP

MANAGEMENT OF **DRILLING SITES**

*This is the first in a series of articles on safely managing all working geotechnical sites, penned for **theGeotechnica** by the experts at the* Equipe Group*. This month we focus on the management of cable percussion drilling sites - focussing particularly on spacial awareness.*

Cable Percussion rigs are still a widely utilised tool when carrying out ground investigations. Unfortunately their working space can be under-estimated which can lead to unnecessary contract conflicts on site, or situations which could lead to unsafe operations. This article aims to provide some guidance, whilst raising some issues to consider when specifying cable percussion boreholes with respect to the required space for the safe operation of this activity.

Whilst ground investigations are being scoped, there is all too often a potential conflict between the plant and equipment required to obtain the data for design, costs and the nature of the site and logistics. Of course, this is a massive simplification of the ground investigation process but where sites have limited access or working areas, proper consideration for the safe set up and operation of the equipment must be carefully planned.

Firstly, it is highly important to note that although there are now only a few companies that supply cable percussion rigs, there are a number of subtle differences in their rigs' respective dimensions, which can lead to problems if they are not carefully considered.

	Dimensions[1]
Travelling length (unhitched)	7.50m to 8.80m
Travelling (hitched)[2]	11.80m to 13.90m
Working Height (under sheaves)	5.20m
Working Height	6.65m to 7.10m
Width (dependent upon tyres)	1.70m to 1.90m

Notes

1. Approximate dimensions provided for general guidance only. Please consult the manufacturer's guidance for the specific rig being used.
2. Based upon Landrover 110/130

Carefully assessing the movement room available to a working cable percussion rig should always be the first

"Whoever is operating the rig must consider how/if the rig can travel safely to the work area."

part of the process. Whoever is operating the rig must consider how/if the rig can travel safely to the work area. Somebody who understands the requirements of the rig must walk the route that the rig must travel to get there – more often than not, this is the driller. Due to the length of the rig (either hitched or unhitched), moving around tight corners, turning through tight gaps at an angle and travelling along narrow access roads with bends and turns can all cause problems. These potential problem areas and tight spots must be highlighted and carefully considered before moving the rig any further. The driller must always ask himself how these problem areas might impact on the safety of the operators and others i.e. consider any delays from the rig slowing down off a highway through a gateway or a rig being towed across a level crossing which has a tight corner on the opposite side or moving onto a highway off a site.

Once at the work site remember that the borehole itself will be approximately 3 to 3.5m from the rear of the engine unit once erected. Therefore try to allow at least 4m from the borehole location to any obstructions such as walls, hedges, slopes, ditches e.t.c.

"To safely set up a cable percussion rig, you must allow 8.50m to manoeuvre the rig into position."

To safely set up a cable percussion rig, you must allow 8.50m to manoeuvre the rig into position. In order to erect the rig, the legs are brought around the rig from their travel position which requires approximately 0.75m on each side. If this requirement is combined with the overall width of the rig then a working width of 3.50m would be sensible. Also take into account where the driller will stand and make necessary allowance for them to work safely without obstruction on that side.

Once erected the rig's footprint will be approximately 2.50m x 4.50m which does not make any allowance for working room and trestles for rods. If a further 4m is allowed for rods and working room then a sensible work site length would be 8.5m.

REQUIRED SPACE = 4.5m (width) x 8.5m (length)*

**It should also be remembered that the dimensions discussed above could represent a typical situation, however, projects are varied. Some will require more equipment and/or additional ancillary equipment and allowance should be made for the storage and safe operation of such at the work area if required.*

The third dimension to discuss is the working height. The working height dimension should not be taken in isolation as specifyers and operators should always remember to take a good look up as well as down.

"Care should be taken to assess whether anything may restrict the rig as it is being raised such as cross beams in a warehouse..."

Care should be taken to assess whether anything may restrict the rig as it is being raised such as cross beams in a warehouse, cables, tree branches e.t.c. and sufficient allowance in the overall working room and rig positioning adjusted as necessary.

COMPUTATIONAL LIMIT ANALYSIS COMES OF AGE

*Dr Tom Pritchard is a Senior Engineer at engineering software house LimitState Ltd. Here Tom writes for **theGeotechnica**, describing why Computational Limit Analysis is quickly becoming an indispensable tool for geotechnical engineers.*

Beyond automated hand calculations

Computational limit analysis (CLA) techniques can now be used to rapidly determine the critical failure mechanism and margin of safety for almost any type of geotechnical construction. This means that engineers can move beyond simple 'hand-calculation' methods, each suited for a specific problem type, but without needing to resort to much more complex and potentially time-consuming techniques such as non-linear finite elements (see Figure 1). In practice CLA can for example help consultants verify and optimise ultimate limit state (ULS) designs, help contractors make rapid and informed decisions when on site or when designing temporary works, or help offshore engineers perform detailed parametric studies for geometrically complex problems.

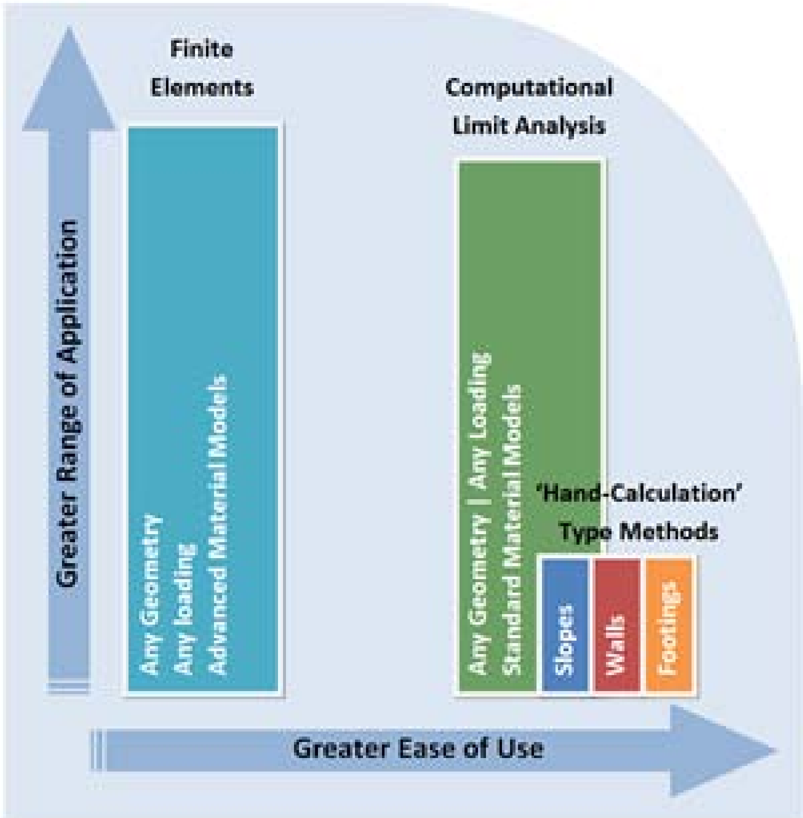


Figure 1 – Where does computational limit analysis fit in?

Geometrical freedom

Experienced geotechnical engineers have become accustomed to categorising a given design problem as, for example, 'a slope problem', 'a retaining wall problem' or perhaps 'a bearing capacity problem'. However, real-world problems often do not fit neatly into these categories - and in practice behaviour can be significantly more complex than assumed in a simple analysis.

"...real-world problems often do not fit neatly into these categories - and in practice behaviour can be significantly more complex than assumed in a simple analysis."

Figure 2 shows a terraced slope example. The author has often presented this at industry meetings - along with the question: "how would you analyse this problem?" The most common responses are that this should be modelled either as 'a slope problem' or as 'a retaining wall problem', relying on one of the numerous available automated hand-calculation software packages to check the design. However, CLA obviates the need to pigeon-hole a problem in this way. Most importantly the CLA mechanism identified shown in Figure 2 is quite different - and in this case more critical - than one which could be identified using automated hand-calculation software.

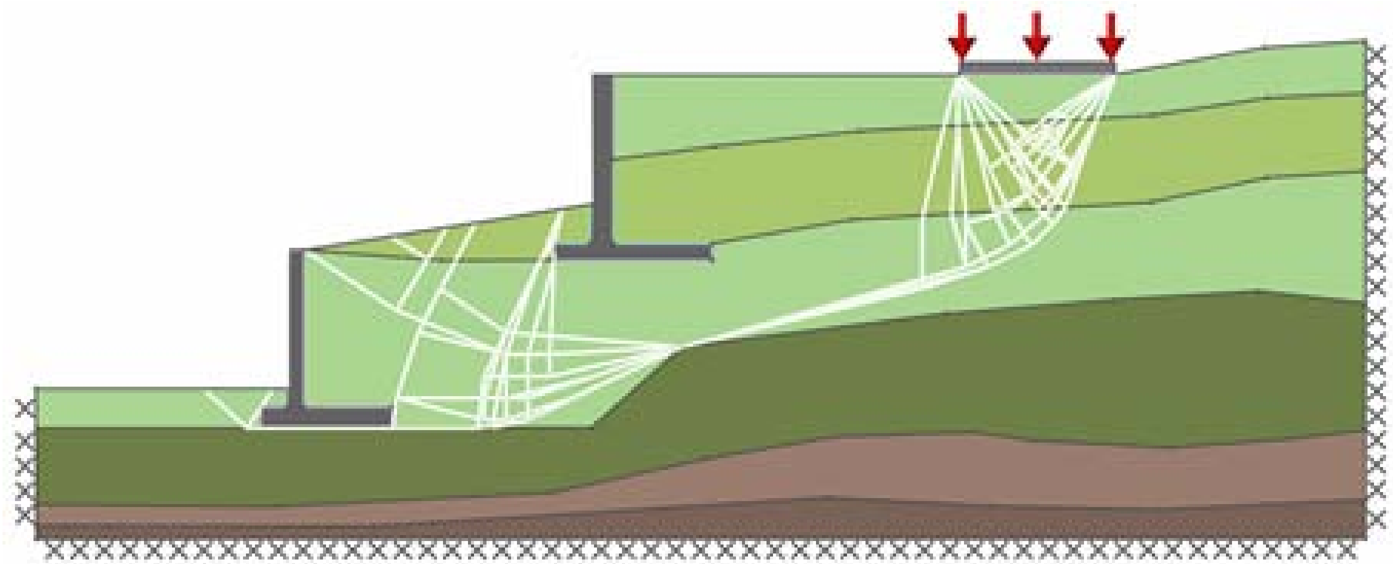


Figure 2 – Terraced slope – is this the failure mechanism you would have identified?

"Many other 'non-standard' failure mechanisms can be identified using CLA."

Many other 'non-standard' failure mechanisms can be identified using CLA. For example, Figure 3 shows an embankment problem where the critical mechanism involves 'extrusion' of a soft clay layer, rather than a conventional slip-circle type failure mechanism.

New means of assessing safety

To establish the margin of safety in an ultimate limit state analysis there is a need to drive the geotechnical construction to collapse by some means. Normally this has been achieved by increasing one or more loads in the problem (e.g. by increasing a surcharge load, such as that shown in Figure 2, or the self-weight of one or more bodies of soil). This then gives the margin of safety as a factor on that load or self weight. While the factor on load is the factor of safety often quoted for e.g. foundations, in some cases this form of factoring can prove problematic.

Consider an example of a brick lying on a wooden plank (Figure 4). If one edge of the plank is lifted and the plank's angle to the horizontal (α) is gradually increased, the brick will remain stable until the plank angle reaches the angle of friction between the brick and the plank (ϕ). At this point the brick slides and beyond this point the system is inherently unstable. Therefore, the situation is either stable or unstable, and is entirely unaffected by the weight of the brick i.e. attempting to drive the failure of the problem by increasing the self- ▶▶

"At this point the brick slides and beyond this point the system is inherently unstable."

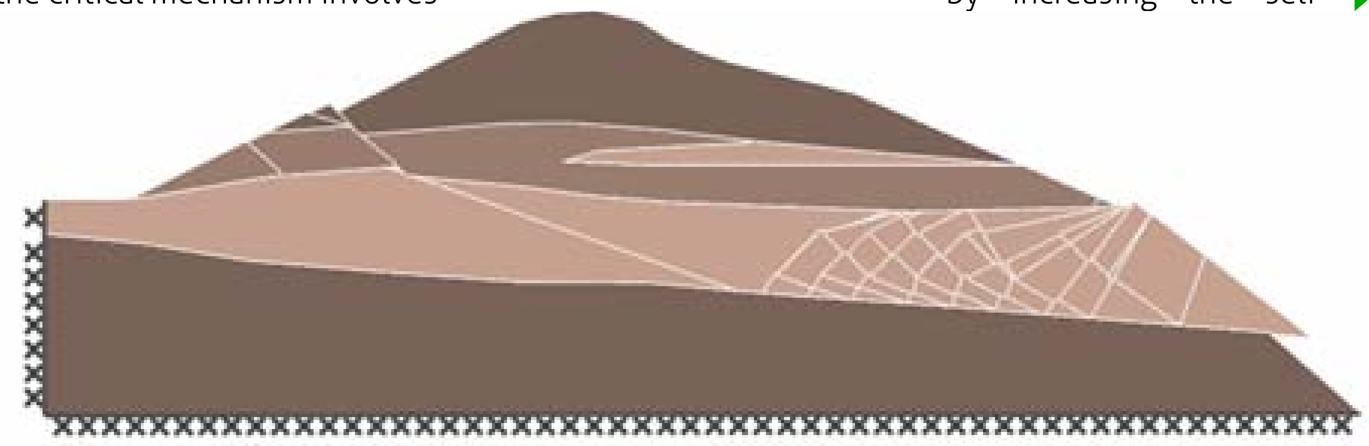


Figure 3 – Embankment problem – failure mechanism involving 'extrusion' of a soft clay layer

weight of the brick will not be successful. This analogy can be applied to the stability of a slope comprising a purely

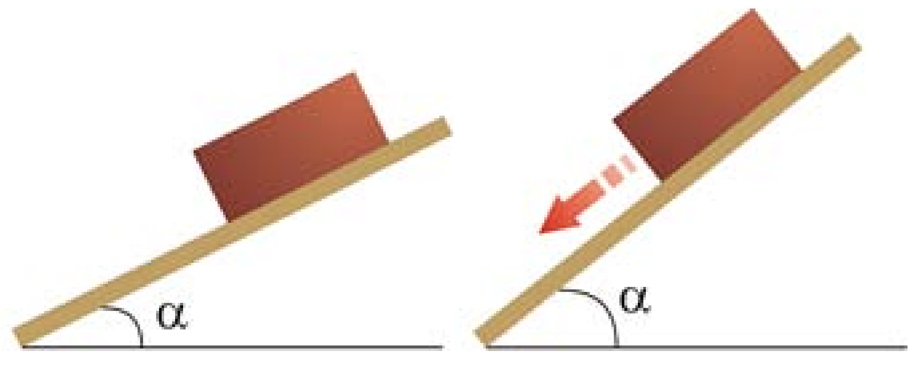
"Here, increasing the self-weight of the soil has no influence on stability..."

frictional soil. Here, increasing the self-weight of the soil has no influence on stability as a slope of a given angle is either stable or unstable whatever the density of the soil. In situations where no other (external) loading is applied, this makes identification of the critical failure mechanism using CLA very difficult.

To make the CLA method easier to apply to such problems, an important recent development in LimitState:GEO – the only commercially available geotechnical CLA software - has been to allow users to initiate collapse by reducing material strength rather than

"This means that solutions in the form of traditional global factors of safety can now be obtained..."

by increasing load. This means that solutions in the form of traditional global factors of safety can now be obtained, facilitating direct comparison with traditional approaches. This enhancement marks a real 'coming of age' for CLA in general and LimitState:GEO in particular. The recently released LimitState:GEO 3.0 also includes a range of other new features, including a much more flexible water modelling capability.



(a) Stable $(\alpha < \phi)$ (b) Unstable $(\alpha > \phi)$

Figure 4 - Stability of a brick on a plank: (a) stable, (b) unstable

Under the hood

At the heart of all CLA software is an analysis engine. In the academic literature, the most popular CLA technique is the so-called 'Finite Element Limit Analysis' (FELA) method. This approach typically involves only three material parameters (unit weight and two material strength properties, assuming a Mohr Coulomb material model) along with the definition of a finite element mesh. Unfortunately, the layout of the mesh can often have a significant influence on the accuracy of the solutions that are obtained – an issue that was somewhat glossed over in early academic papers.

A more recently developed alternative to FELA is the 'Discontinuity Layout Optimization' (DLO) limit analysis procedure. This is used in LimitState:GEO and can be used to directly obtain accurate solutions in the form of slip-line collapse mechanisms which are familiar to all geotechnical engineers. When using DLO there is no requirement on the engineer to adopt 'tailored' meshes to obtain accurate solutions as the critical collapse mechanism is determined from a mind-boggling number of

"Even on a modest desktop PC, problems containing over two to the power of one billion potential slip-line arrangements can be considered..."

possible layouts. Even on a modest desktop PC, problems containing over two to the power of one billion potential slip-line arrangements can be considered, which is truly incredible given that there are only an estimated two to the power of 80 grains of sand on the earth!

Ultimate Limit State design

The adoption of Eurocode 7, which became mandatory throughout Europe in 2010, represents a significant change in the way geotechnical design is performed. Eurocode 7 specifies a general set of partial factors that are not specific to any particular type of problem, meaning that a wide range of geotechnical stability problems can be considered. This philosophy is highly suited to general purpose approaches, such as CLA, where the engineer has the benefit of being able to model all possible ULS failure modes, rather than only a narrow subset, as is often the case when using techniques that essentially automate hand calculations for particular scenarios (Smith and Gilbert 2011a, 2011b).

By being compatible with the Eurocode 7 philosophy, tools built on a CLA framework, such as LimitState:GEO, can easily incorporate:

- Built in Eurocode 7 'problem-agnostic' partial factor sets
- Eurocode 7 load descriptions (permanent, variable, accidental)
- Favourable and unfavourable load classifications
- The ability to check multiple Design Approaches / Combinations in a single analysis

Furthermore, compatibility with the Eurocode 7 framework enables CLA procedures to readily be used in conjunction with other limit state design methodologies.

Soil-structure interaction

"Problems involving structural elements can present a particular problem for automated hand calculations."

Problems involving structural elements can present a particular problem for automated hand calculations. For example, in the case of a nailed slope a simple 'two-wedge' failure mechanism is often assumed, but with modern CLA software there is no need to make this kind of simplification (which in general will be non-conservative, since other, more critical, failure mechanisms may exist). Also structural elements can be included in an analysis model directly (rather than just their anticipated effects), and useful post-analysis data can be displayed - e.g. bending moments in a sheet pile wall, as shown in Figure 5.

Highly visual output

The identification of slip-lines provides CLA with a highly visual means of conveying the critical failure mechanism to the engineer. Furthermore, these mechanisms can be readily animated to provide engineers with an even greater understanding of the problem in hand. This, coupled with the generally quick solution times required by CLA, allows 'what if' scenarios to be rapidly investigated, allowing users to rapidly build up an insight of the likely modes of response, and the key parameters influencing safety.

Closing remarks

In summary, CLA has developed rapidly in recent years. The

"The technique is now helping engineers worldwide to rapidly assess geometrically complex geotechnical construction..."

technique is now helping engineers worldwide to rapidly assess geometrically complex geotechnical constructions - without the need to resort to simplistic automated calculation methods on the one hand, or significantly more complex methods such as finite elements on the other. ■

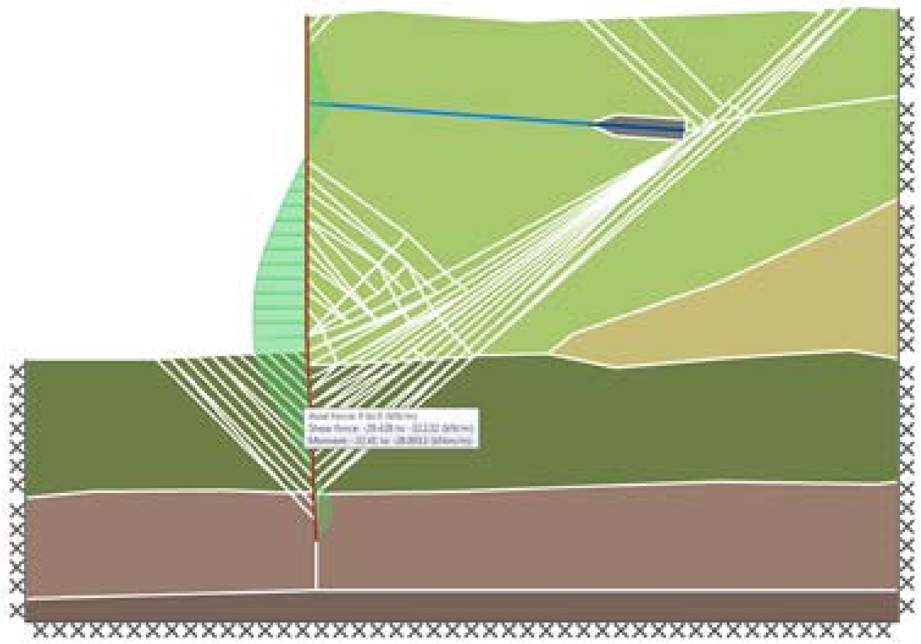


Figure 5 – An anchored sheet pile wall, showing bending moment distribution in the wall.

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CONTAMINANT OF THE MONTH:
ARSENIC
PROPERTIES, USES, TOXICITY AND ANALYSIS

*Writing for **theGeotechnica** once more is Hazel Davidson of [Derwentside Environmental Testing Services](). This month, Hazel discusses the properties, uses, toxicity and analysis of arsenic.*

Arsenic is highly poisonous to multicelled organisms, both plants and animals, and is therefore of significant environmental concern.

"Although often referred to as a metal, and included in metal suites for analysis, it is actually a metalloid..."

Although often referred to as a metal, and included in metal suites for analysis, it is actually a metalloid, and can exist in different valency states, with a complex chemistry similar to phosphorus. The most usual elemental forms are a metallic grey crystalline solid, and a darker grey amorphous solid, but it is much more common in the natural state as an ore combined with sulphur, for example, as iron arsenic sulphide (arsenopyrite), but there are many others. The most common forms affecting human health are the oxides, arsenate (As_4O_{10}) and arsenite (As_4O_6), but it can also form a gas, arsine (AsH_3), which is also highly poisonous. However, possible exposure to arsine is considered to be very rare.

Historically, arsenic was used as a deliberate poison in the Middle Ages, and there is some debate as to whether Napoleon died from drinking arsenic tainted wine. It was thought to have some beneficial medical effects, and more recently, it was used in small doses to treat some cancers.

Properties and Uses

Elemental arsenic has an atomic number of 33, atomic weight of 74.92, and a melting point of $816^{o}C$. It is used extensively as a semiconductor in car batteries and strengthening copper and lead alloys. Because of its toxicity to a wide range of organisms, it was widely used in pesticides, herbicides and wood preservation (usually as copper chrome arsenate – CCA), although these are now being phased out, due to the toxic properties for humans, although in 2003, the UK was still the largest user in the EU. Dimethylarsenic acid is known as Agent Blue and was used extensively as a herbicide in the Vietnam war.

"Because of its toxicity to a wide range of organisms, it was widely used in pesticides, herbicides and wood preservation..."

Toxicity

Inorganic arsenic compounds (commonly, arsenate) react at a cellular level to interfere with the production of ATP and also react with a range of proteins to inhibit their activity. Thus, by a variety of mechanisms, arsenic compounds impair the respiration of cells, leading to muscle weakness, cyanosis, and eventually, multiple organ failure and death. In addition, inorganic arsenic is carcinogenic in humans, with long term exposure producing lung tumours via inhalation, and a range of cancers via the oral route, particularly cancers of the skin, bladder and lungs. Organic arsenic is approximately 500 times less toxic than inorganic arsenic compounds and is not a significant issue for human toxicity.

"Thus, by a variety of mechanisms, arsenic compounds impair the respiration of cells..."

The Index Dose for arsenic is 0.3 µg/kg body weight/day, based on the UK Drinking Water limit of 10 µg/l.

Soil Guideline Values (SGVs)

The Environment Agency Report SCO 50021/ arsenic SGV was published in 2009 and provides the following SGVs:

Land Use	Soil Guideline Value (mg/kg dry weight)
	Inorganic Arsenic
Residential	32
Allotment	43
Commercial	640

Based on a sandy loam soil with 6% soil organic matter (SOM), and based only on a comparison of oral and dermal soil exposure with oral Index Dose.

The inhalation of dust makes a very minor contribution to total exposure for all land use scenarios at a soil concentration equal to the SGV, and therefore would make a negligible additional contribution to the total cancer risk.

Natural geology and the impact of mining activity have resulted in elevated arsenic levels in several regions of the UK. The Soil and Herbage Survey demonstrated levels of arsenic between 0.5 mg/kg and 143 mg/kg in rural areas, with a mean of 10.9 mg/kg, and a more reduced range of 1.75 mg/kg to 32 mg/kg in urban soils, but with a similar mean of 11.0 mg/kg. Hotspot areas such as Camborne in Cornwall, demonstrated levels as high as 320 mg/kg, due to extensive mining activity.

Oral bioaccessibility is the fraction of a substance that is released from the soil during processes like digestion into solution, making it available for uptake by the body. This is of particular interest in the UK because of the large areas of land where ▸▸

"This is of particular interest in the UK because of the large areas of land where arsenic concentration in soil is naturally elevated."

arsenic concentration in soil is naturally elevated. In vitro methods of measuring bioaccessibility depend either on milder chemical extraction tests, giving 'available' metal concentration, or by mimicking the gastrointestinal conditions in the human

"At present, the Environment Agency is undecided as to the validity of these methods..."

stomach/intestine. At present, the Environment Agency is undecided as to the validity of these methods, but if the tests are performed by an accredited laboratory in accordance with guidelines for good practice, they consider that the results can be useful as part of a "lines of evidence approach" to evaluating site-specific risk, including the sensitivity of any quantitative risk assessment.

Arsenic in groundwaters

However, of more concern environmentally, is the widespread presence of arsenic in groundwater systems throughout the world. Inorganic arsenic compounds are very soluble in water, and due to the prevalence of natural arsenic in the ground, plus human activity, there are many areas of the world with severe arsenic issues. A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water.

The Drinking Water level of 10 µg/l is not a minimal risk level, which has been calculated at 0.003 µg/l, equivalent to a lifetime risk of developing cancer of 1 in 100,000. The Drinking Water level equates to a lifetime cancer risk of 40 – 400 in 100,000.

Many water treatments exist, such as flocculation, precipitation and filtration, adsorption onto iron oxide or alumina, ion exchange, or

"However, all such systems carry significant costs and funds are not always available in many countries."

reverse osmosis. However, all such systems carry significant costs and funds are not always available in many countries.

Analysis

Arsenic is generally analysed by ICP (Inductively Coupled Plasma Emission), as part of a suite of toxic metals. Waters are filtered, acidified and analysed by ICP-MS (Mass Spectroscopy) to achieve lower detection limits, whereas soils are digested in a concentrated hydrochloric acid and nitric acid (aqua regia) mixture, filtered, and then analysed by ICP-OES (Optical Emission Spectroscopy). ICP is an aggressive method, heating the sample to 10,000oC in the plasma, so is a good choice for analysis of total concentrations (as long as the compounds are solubilised by the acids).

Summary

Arsenic compounds, particularly in the inorganic form, are prevalent throughout the earth's surface and can cause death or severe illness due to ingestion, either of soil or contaminated groundwater.

"Because of this abundance, drinking water limits and soil guideline values are set at many times the minimal risk values..."

Because of this abundance, drinking water limits and soil guideline values are set at many times the minimal risk values, as it would be impossible to remove arsenic to an appropriate level. This has led to considerable interest in bioaccessibility methods, as these are thought to give a better reflection of likely human uptake. ■

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In-vitro methods for the measurement of the oral bioaccessibility of selected metals and metalloids in soils: a critical review (Environment Agency and British Geological Survey, 2003a)

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