SUSTAINABILITY – WHAT DOES THIS MEAN FOR THE DEEP FOUNDATIONS INDUSTRY?

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Sustainability means different things to different people involved in a construction project. For example, a land developer may have a different view on the outcome of the design in terms of sustainability than the Engineer. Achieving sustainability on any project thus either leads to conflict between competing interests or demands cooperation between the economic and technical sectors involved in any project. When considering the foundations to a building or a bridge, it is less clear what aims of sustainability can be achieved compared to the building or bridge itself. Deep foundations are just one part of the topic of sustainable geotechnics. The most likely avenues for successful sustainable deep foundations are for them to become cheaper or quicker solutions than traditional ones, or to combine them with other parts of sustainable geotechnics to realise tangible economic benefits. Improvements in commercial and procurement activities, and in training, are encouraged to help to realise sustainable solutions that offer more than only environmental benefits.

INTRODUCTION

Sustainability generally means meeting present needs without compromising future needs. The probabilities and consequences of negative impacts on the environment and on society over the short term and in the long term can be assessed and mitigated, but mitigation will often induce additional cost. When assessing these impacts and their risks we cannot know what technologies will be available say 1000 years into the future. It is difficult to have a personal connection with 1000 years into the future, which is about 40 generations of our society. It is much easier to have a connection with 100 years into the future, which is only about 4 generations, i.e. affecting your great, great grandchildren. The additional cost and one’s personal concept of sustainability, its importance and its potential impacts means that the value of mitigation will not be the same for different people.

As well as having a different meaning to different people, sustainability also means different things to the different parties involved in a construction project. For example, a land developer is likely to have a different view on the outcome of the design in terms of sustainability than the Engineer, unless these result in tangible economic benefits for the developer. Achieving sustainability on any project therefore either leads to conflict between competing interests or demands co-operation between the economic and technical sectors involved in any project. For sustainability to be achieved routinely the latter must prevail.

When designing or constructing a building or a bridge it is reasonably clear what sustainability is to achieve, i.e. to negate, or at least to minimise, the impact on the environment for future generations. This would normally involve reducing the use of new materials, minimising the production of new waste, and increasing the use of waste or second-hand materials. Here we are normally dealing with man-made materials whose behaviour can be rigorously tested and then idealised for design with sufficient safety factors to allow for construction imperfections. Importantly, new materials or construction methods can be trialled away from the site and still be considered directly relevant to any project.

When considering the foundations to the building or the bridge, which by definition need to interact with the ground whose behaviour cannot be dictated by man, then the aims of sustainability are the same but it is less clear how they should be achieved. A simple example is the driven pile which does not produce spoil waste, but is likely to be too noisy to be acceptable in an urban environment. This then begs the question should the public accept the nuisance of short term pile driving to achieve a more sustainable foundation? Additionally, the question has to be asked can the deep foundations industry develop its techniques and products to help make them more acceptable and appropriate more often than is possible now? This may indeed be possible for the driven pile example as shown in Figure 1.

Deep foundations are just one part of the topic of sustainable geotechnics. The most likely avenues to success for sustainable deep foundations are for them to become cheaper or quicker solutions than traditional ones, or to
combine them with other parts of sustainable geotechnics to realise tangible economic benefits. Such sustainable geotechnics includes environmental geotechnics, ground source energy, understanding embodied energy, reducing material quantities, use of materials with reduced embodied energy, use of recycled materials, lean design, the re-use of foundations, and maintaining heritage and archaeology.

**SUSTAINABLE GEOTECHNICS**

There are various methods available for assessing the sustainability of projects, products or organisations, such as LEED, BREEAM, CEEQUAL, plus many others. One example of these is the Arup design tool SPeAR (Sustainable Project Appraisal Routine) which investigates economic, social, environmental issues and the impact on natural resources, see Figure 2.

Such tools are essential for assessing sustainability at a particular point in time and indicate strengths and weaknesses allowing informed decision making on issues relating to sustainability. This should promote sustainable practices but unfortunately these tools are limited in terms of their direct applicability to geotechnics and to deep foundations.

Currently sustainable geotechnics is normally dealt with outside of the sustainability assessment methods used for buildings and for civil engineering structures, because these have generally been designed for master planning and not with the specifics of ground engineering in mind. Thus at the moment it is mainly up to the geotechnical industry to promote their sustainable solutions separately.

This paper examines these issues and some examples will be described of sustainable deep foundations. Some recommendations are made regarding the future of the deep foundations industry and sustainability.

**Figure 2: SPeAR diagram**

Sustainable geotechnics can be thought of as comprising:
- environmental geotechnics
• ground source energy
• understanding embodied energy
• reducing material quantities
• use of materials with reduced embodied energy
• use of recycled materials
• lean design
• re-use of foundations
• maintaining heritage and archaeology.

Each of these is briefly described and then examples are given of how each has been applied to deep foundations.

**Environmental geotechnics**
Environmental geotechnics can be considered as comprising two parts: assessing and then regenerating sites. The cost of purchasing brownfield or contaminated land and the cost of regenerating the land so that it is appropriate for the end use are intimately linked with the commercial viability of the development.

Site assessment not only includes desk study and investigative work, but requires a technical and commercial understanding of what is, and what is not, practical to regenerate the land.

Regeneration of the land is the part of most interest to the deep foundations industry. This could be by forming a barrier around the perimeter of the site, say by forming a deep cut-off wall, or by treating the ground itself using either in-situ soil mixing or ex-situ soil treatment.

**Ground source energy**
Near surface ground energy and deep geothermal energy are both renewable sources of energy. The amount of near surface energy available on any site depends on the ground and groundwater conditions, and whether this is technically or economically viable will also depend upon the energy requirements of the building.

Near surface ground source energy systems may be closed systems where a heat transfer fluid is re-circulated between the building and boreholes up to say 200m in depth. Alternatively the near surface ground source energy may be derived from an open system where groundwater is pumped directly from an aquifer up into the building.

Deep geothermal energy systems require a power station to be built with boreholes several kilometres deep in a location where the geology is appropriate for the technique being used. There isn’t one such power station present in the United Kingdom (UK) yet.

The use of near surface ground source energy is an emerging, but fast growing, market in the UK. Up-front capital expenditure will be higher than for conventional sources of energy, but there should be a net cost saving after a few years of operation. Cost plans that cannot take into account the future savings will be disadvantaged and currently without legislation such as the Merton rule this market would be much smaller than it currently is.

Constructing deep boreholes for these systems has become an important source of work for many drilling contractors. The use of energy piles is also becoming more widespread, although the impact on pile capacity by changing ground temperature needs to be treated with caution as this is not currently well understood.

**Understanding embodied energy**
There are many embodied carbon dioxide and embodied energy calculators available. The main difference between them is the data that is used, i.e. the embodied CO$_2$ or embodied energy value for each material, and the type of building or sector or construction method that the calculator has been specifically designed for.

Calculation procedures are straightforward, but the time is important when the calculation is carried out in design development and as construction products are finalised. The primary purpose of these tools is to compare solutions and products so that an informed decision can be made in terms of cost, programme and sustainability.

Embodied energy is generally preferred over embodied carbon dioxide because it considers both the impacts of the building fabric plus those with the operation of the building. However, for foundations there is not normally any ongoing operational requirements so either would generally be appropriate when comparing different foundation solutions.

**Reducing material quantities**
A key target of sustainability is to reduce the use of materials. This can be achieved by a variety of methods including the use of alternative materials, increasing material testing, reducing safety factors, and/or increasing the material design properties. For any of these the sustainability benefits must be assessed in context with any technical or economic impacts.

**Use of materials with reduced embodied energy**
There is now data readily available giving the embodied carbon dioxide and embodied energy
associated with most construction materials. One example is the Inventory of Carbon and Energy published by the University of Bath in the UK.

However, a direct comparison of different materials or products is not encouraged. Instead elements providing the same function should be compared; for example do not compare concrete and steel but compare say a concrete pile to a steel pile noting that their geometry will certainly be different.

**Use of recycled materials**
The use of recycled materials as a replacement or a partial replacement of new materials is obviously to be encouraged.

The most common example of this is replacing cement with pulverised fuel ash or ground granulated blast furnace slag. The reason for this has, however, not been for sustainability, but due to the fact that these replacement cement materials are cheaper than cement and also offer technical benefits such as improvements in the durability characteristics.

Cement replacement is frequently used in concrete replacement piles but is used in limited quantities in preformed concrete displacement piles. Cement replacement for soil mixing importantly requires specific site trials as part of the design.

**Lean design**
Unduly conservative design cannot be sustainable because it will result in the increased use of materials and energy in construction. Advanced design tools to optimise the design, combined with appropriate safety factors, testing and monitoring, is encouraged because this will minimise the use of materials and energy. However, it must be noted that this requires increased technical expertise for the design phase, and just as importantly increased site competence for managing unforeseen variations and unexpected occurrences during construction.

One example of lean design is the use of the observational method, as described by Nicholson et al (1999), which can be used to optimise the design and propping of embedded retaining walls for example.

It should be noted that design codes, legislation or local industry practices may prevent the application of lean design. In such cases industry should challenge these barriers.

**Re-use of foundations**
With good records and appropriate on site investigation and testing it may be possible to re-use the existing foundations for a new development. The cost and programme benefits are obvious but the technical and insurance implications may be significant, sometimes influencing the design and financing of the new building. Detailed guidance on the re-use of foundations has been published by Chapman et al (2007) and by Butcher et al (2006).

If foundation re-use is to be considered it will likely increase the time and costs associated with the development of the design. At various stages of the investigation and design development there will need to be close liaison between the technical and commercial sectors to ensure that foundation re-use remains appropriate.

**Maintaining heritage and archaeology**
In historical cities it is important not to damage their heritage and for deep foundations this often means either not damaging at all, or at least minimising the damage to, existing archaeology.

This may mean that new ground floor slabs or basement slabs in a development cannot be any lower than that provided previously on earlier developments on the site. New piles or groups of piles may be limited in size so that they remain within the footprint of any existing piled foundations. Often monopiles at column positions are preferred, combined with suspended ground beams and floor slabs.

**SUSTAINABLE DEEP FOUNDATIONS**
Case studies are given below as examples of how sustainable deep foundations or other geotechnical processes have either provided a cheaper or quicker foundation solution in their own right, or have formed part of the sustainable geotechnical provision for the project.

**Environmental geotechnics**
As an alternative to pile foundations and to ground treatment, soil stabilisation was undertaken by Roger Bullivant to provide the bearing medium for a hospital extension in north-east England on brownfield land. The ground was rotavated and subsequently quicklime/cement added to improve strength. A 19T roller was then used to compact the material.

The ground was modified in 300mm deep layers to increase the California Bearing Ratio to around 30%. A 100mm deep recycled aggregate capping layer was then placed on top. This aggregate contained no virgin material and was incinerator bottom ash aggregate supplied from local household waste incineration plants.
Energy piles have been used in central Europe since the 1980s. They were introduced into the UK about eight years ago, see Suckling and Smith (2002). Energy piles are a combination of structural piles and the closed near surface ground source energy system. In the UK the amount of energy that can be realised from piles alone is not likely to be sufficient for a building much larger than say four storeys. For much larger developments piles can still be used to provide energy but they need to be combined with other sources of energy, either traditional and/or renewable.

Figure 4 shows the construction of over 200 energy piles for a large commercial development in central London. Piles are constructed by Cementation Skanska who also designed the piles to carry the building loads. Another company Geothermal International designed the energy aspects of the piles.

**Calculating embodied energy**

Stent have produced a carbon dioxide assessment tool, specifically designed for their piling products in the UK market, see Figure 5, called Green Siesta. The tool assumes average CO₂ values for concrete and steel based upon typical values for the UK. However, when the concrete mix or steel supplier is certain, as is the case for their precast concrete driven piles which are manufactured in-house, then specific CO₂ values can be used in the assessment.

Figure 4: Construction of energy piles

Figure 5: Example of Green Siesta calculation

The impacts of transport and fuel use by plant is also taken into account, as well as spoil waste if any is produced. However, the largest contributor of CO₂ is normally from the cement in concrete.

Undertaking site specific calculations, not generic ones, is recommended due to the unique
The combination of ground conditions and building loads present on a site. It is not obvious when one pile solution will be better or worse in terms of CO₂ impact than another pile solution, and sometimes the results are surprising.

**Reducing material quantities**
The most common sustainable deep foundations to date have been those that have innovatively saved concrete material.

In east London Bachy Soletanche have designed, constructed and tested a ribbed bored pile founding in clay, see Figure 6. The test showed that the ribbing had the effect of increasing the shaft resistance of the piles by 25%, see Borel at al (2008).

When the thickness of clay is limited, the use of ribbing to increase capacity may then mean that the piles do not need to penetrate into soils underlying the clay which may be unstable and water bearing and so require the use of a support fluid. Consequently ribbed piles may well prove to be significantly cheaper and quicker than conventional bored piles, as well as being more sustainable.

The City SuRe pile is a large diameter hollow bored pile being promoted by City University, London. The capacity of large diameter friction piles is limited by the available shaft friction and end bearing load transfer between the pile and the ground, and is often much less than the structural capacity of the concrete pile. To try to achieve compatibility between the structural and the geotechnical capacity the focus in the deep foundations industry has to date been on improving the shaft friction load transfer, often by shaft grouting or by forming ribbed piles, or by increasing the base capacity by forming underreams.

An alternative way of achieving compatibility and reducing material is the hollow pile which optimises the volume of concrete provided to match the geotechnical capacity. Figure 7 shows the construction of a 1200mm diameter concrete hollow test pile with an 800mm void in the centre. The performance of this test pile was comparable to that of an adjacent conventional solid concrete test pile of the same dimensions.

**Figure 6:** Ribbed pile being constructed

**Figure 7:** Instrumented City SuRe pile being constructed by Stent
Use of materials with reduced embodied energy

It has proved difficult to date for the author to get meaningful unbiased data regarding the embodied energy associated with steel used in construction in Europe. What is clear though is that if the steel can be proven to be recycled, and if there will be an opportunity to remove the steel element at the end of its design life, then there is no doubt that a steel pile is preferable in terms of sustainability than a concrete pile.

The use of steel screw piles has grown very quickly in the UK in the last decade, particularly in the rail sector. There have been other innovations in steel piling, such as that by Dawson shown in Figure 8. Here six Hoesch Larssen 43 sheet piles have been individually pressed into the ground, through a steel template located on the ground beside a live motorway, to form a steel box pile foundation to which a traffic sign or gantry can be directly attached. This is a more sustainable solution than using concrete piles or a concrete foundation.

Use of recycled materials

The use of recycled materials in vibro stone columns has been gradually developing in the UK, as described by Serridge (2006). It is currently only economic to use such aggregates, rather than primary aggregates, when they are available within say 25 miles of the site. If further away then currently the specification of recycled aggregates would unfortunately increase the cost of the ground improvement.

The best opportunities to date for the use of recycled aggregates in vibro stone columns in the UK have been with recycled spent rail track ballast and crushed concrete. The recorded compressibility moduli for stone columns, constructed using recycled spent railway ballast and concrete, are similar to values reported and previously adopted in design for natural primary aggregates. In the longer term there is a need to further develop performance-based specifications to optimise the use of recycled aggregates for vibro stone columns.

Storage conditions for recycled stone column aggregates should be such that contamination and introduction of excessive fines is avoided, which would otherwise lead to poor inter-granular contact within the completed stone column. The fines content has a significant effect on the angle of internal friction of the stone column material and therefore its load carrying capacity and the settlement potential of the treated ground.

Figure 9 shows spent railway ballast being used by Pennine Vibropiling in stone columns on a contract in the UK.

Figure 8: Jacked steel foundation next to a live motorway

Lean design

For a large infrastructure project in Australia, one particular section of a cut and cover structure required a 20m deep excavation in Tuff rock with a roof slab at about 10m depth. Soil was to be backfilled on top of the roof slab so as to reinstate the original ground surface. The width of the structure is about 40m with a wall running approximately down the centre.

It would have been relatively straightforward to design and construct a flat concrete roof spanning from the side walls to the central wall. It is estimated that such a slab would have needed to be several metres thick. However, it was decided to design and construct a much more complex and riskier two span concrete arch structure, see Figure 10.
The design of such a structure required a detailed soil-structure interaction analysis that took several months to complete. The construction required significant control on site to ensure that collapse from uneven loading did not occur. However, a significant amount of concrete, with its high embodied energy, was saved.

**Re-use of foundations**

There are now many case histories where after a detailed investigation and assessment the existing foundations have been either completely or partially re-used to support a new development.

A key part of the investigation process will be to integrity test and then load test a proportion of the existing foundations. When preparing old piles for testing it is the author's experience that a great deal of care and attention is needed to prevent causing damage to the pile, as they tend to be lightly reinforced, see Suckling and Gwynn (2006).

Coring through and removing existing slabs and piles, see Figure 12, costs more money and adds more time to construction, as well as often causing nuisance by noise and/or vibration. The effects of such nuisance can be mitigated by undertaking these activities only at specified times and by developing and maintaining suitable tools and equipment.

**Figure 10:** Finite element modelling of two span concrete arch

**Figure 11:** Load testing of a 50 year old concrete pile

**Figure 12:** Coring through existing piles

**THE DEEP FOUNDATIONS INDUSTRY AND THE FUTURE**

**Climate change v recession**

At the time of writing this paper the world is in recession. The effects of climate change have of course not gone away but man's immediate concerns regarding both individual and company
welfare have unfortunately resulted in less attention on matters relating to sustainability. This means that all involved in construction need to develop sustainable solutions which result in tangible economic benefits.

Regarding deep foundations, for the reasons cited earlier, this is not straightforward and it would be easy for the industry to turn away from sustainability and to only offer solutions and products that have always been available. However the prospect of incoming legislation, and the highly competitive and innovative nature of the foundations market, is likely to resist such inertia, and it is hoped that the recession may result in a plethora of new more sustainable (and cheaper) techniques becoming available.

**Contractual arrangements and relationships**

The author acknowledges that he has no influence on commercial matters in the construction industry. However, if the economic benefits of sustainable solutions are to be realised then those who do influence commercial aspects must be encouraged to allow sensible amounts of time for tendering, for design development and, if necessary, for site specific trials.

This is particularly important for foundations as each project will have its own unique combination of ground conditions and loads to be resisted. The author’s experience is that brainstorming workshops between the commercial, contracting and technical parties can be fruitful, producing improved economic and sustainable solutions. This could be part of a partnering arrangement or as part of the process of appointing the designer and choosing the preferred contractor. The earlier this is done the more opportunities there will be to influence sustainability, as shown in Figure 13;

![Figure 13: Opportunities for influencing sustainability during a project](image)

**Training in sustainability**

For all geotechnical organisations training in sustainability of experienced senior staff involved in planning and communicating with outside parties will be essential. A key outcome of this training will be to enable them to understand and communicate the economic, as well as the technical, benefits that suit the needs and desires of each of the other interested individuals and parties, and these will all be different.

Similarly training of junior staff to enable them to progress sustainable development will also be essential. The particular needs of all this training will vary depending on the type of organisation and the experience of the individual.

**CONCLUSIONS**

Sustainability means different things to different people and parties involved in a construction project. For example a developer may have a different view on the outcome of the design in terms of sustainability than the Engineer. Achieving sustainability on any project either leads to conflict between competing interests or demands co-operation between the economic and technical sectors involved in any project.

When considering the foundations to a building or a bridge it is not clear what aims of sustainability can be achieved compared to the building or bridge itself.

Deep foundations are just one part of the topic of sustainable geotechnics. The most likely avenues to success for sustainable deep foundations is for them to be cheaper and/or quicker, or to combine them with other parts of sustainable geotechnics to realise tangible economic benefits; such as environmental geotechnics, ground source energy, use of materials with reduced embodied energy, use of recycled materials, lean design, the re-use of foundations, and maintaining heritage and archaeology.

If the economic benefits of sustainable solutions are indeed to be realised then those who influence commercial aspects must be encouraged to allow sensible amounts of time for tendering, for design development and, if necessary, for site specific trials.

The engineering challenge of a low carbon future will be difficult. The geotechnical and deep foundations industry must commit sometime to developing zero or low carbon solutions because in the near future legislation will force this anyway as government policies align to limit global warming. Those who choose to develop these solutions sooner rather than later face the fact that these will need to compete against less sustainable solutions. The challenge is to see
this as an economic opportunity and to make carbon reduction a routine part of what we do.

The message from the foundations industry to the economic sectors of the construction industry should not be “we want to be sustainable to save the planet and safeguard man’s future”, as important as this message is, but must be “we will be sustainable to save you money”. The deep foundations industry should not wait for legislation to emphasise the need for sustainable construction, and those that do wait may find it impossible to catch up when the legislation does finally arrive.

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REFERENCES


