## $CO_2$ 2. Low carbon

# Geotechnics and sustainability: a short guide

**Andy Smith presents some project-related objectives that geotechnical and structural engineers can use to improve the sustainability of a project's foundations.**

## Introduction

The construction sector has a key role to play in achieving the UK government's target of reaching net zero in greenhouse emissions by 2050, with construction and the built environment accounting for 40% of global greenhouse gas emissions[1].

Foundations represent a proportion of these emissions, with the relative amount varying depending on the ground conditions, the project and the foundation requirements. Construction clients, designers, geotechnical companies, and also their supply chains, have a notable part to play in reducing global emissions[1].

This situation is recognised and supported by Curtins, which is making important steps to reduce the environmental impact of its business and of projects.

Assessment of the lifecycle of carbon is becoming an increasingly important environmental systems analysis tool in the construction sector. Given many geotechnical processes such as earthworks and ground improvement are highly energy- and resource-intensive, geotechnical works can play an important role in increasing the sustainability of building construction practices and moving towards net zero, in close partnership with structural and civil engineering methods.

Various papers describing topics and objectives where geotechnical engineering can contribute to improving the sustainability of a project are summarised in **Table 1**.

From this table it is evident that sustainable geotechnics is an evolving sub-discipline of geotechnical engineering that covers a wide area ranging from improved construction practices and energy geotechnics to retrofitting and reuse of foundations.

This article aims to provide some project-related objectives that can be used by both geotechnical and structural engineers to improve the sustainability of a project. These objectives follow key elements of the IStructE's low-carbon design hierarchy: 'build nothing, build less, build clever, build efficiently and minimise waste'[19].

It should be noted that, as sustainable geotechnics encompasses a wide range of topics, this article cannot cover all the areas related to geo-sustainability. Some of the important topics not covered in detail include sustainable site characterisation, geohazard mitigation, geothermal energy foundations, geo-structures for wind and solar energy, sustainable use of underground space, carbon sequestration, and ethical practices in geotechnical engineering. Readers may find further information about these subjects in the papers listed in **Table 1**.

## Objectives

The objective of this article is to provide information on areas to improve the sustainability of a project from a geotechnical perspective, including:

1) increased scope of site investigation and improved project planning
2) optimised foundation design (ground improvement, reuse of foundations)
3) improved accuracy in setting out
4) reappraisal of foundation design with further testing

### Box 1. Vastint MU3a – Phase 1 (Vastint)

- Curtins undertook pile calculations to demonstrate that piles would be acceptable at half the lengths proposed by the piling contractor, based on results of further ground investigation and geotechnical analysis.
- We worked closely with the piling contractor who agreed that the proposal was acceptable.
- The proposal saved the client significant costs as well as being more sustainable.

5) use of materials with a reduced embodied energy
6) reuse of soils on site.

These elements are often interchangeable, but are discussed individually in this article for ease of reference.

**Increased scope of site investigation and better project planning**
Geotechnical engineers have long bemoaned the lack of appropriate fees and time for comprehensive site investigations, with the consequences of a quick and basic site investigation ranging from increased cost and delay in construction to possible structural failures.

A comprehensive investigation can also lead to a more efficient and sustainable design, as it may allow less conservative geotechnical design parameters to be used at detailed design stage. This will likely also lead to cost savings, resulting in an 'everybody wins' scenario.

To reach this positive result, it is crucial that investigations are properly planned in full coordination with the relevant parties (structural engineer, architect, client) to ensure they are specific to project requirements.

A Phase One Risk Assessment (desk study) is essential before any site investigations are carried out to allow proper understanding of anticipated ground conditions, ground risks and geotechnical design requirements. Initial recommendations for any sustainable methods of construction can be included where appropriate.

It is important to note that desk studies and site investigations are usually carried out at early stages of the project, often before contractor appointment or formal structural design. Multiple stages of investigation may therefore be necessary to fill in any gaps and account for any changes in design.

At Curtins, we have the capacity to do in-house site investigations, which are fully planned in coordination with our civil and structural engineering teams during the lifetime of the project. Where structural engineers do not have this in-house knowledge, a geotechnical engineering consultant should be appointed to manage the process and be the point of contact.

**"A COMPREHENSIVE INVESTIGATION CAN LEAD TO A MORE EFFICIENT AND SUSTAINABLE DESIGN**

**Optimised foundation design**
Once a detailed site investigation has been carried out, it may be possible to optimise foundations by avoiding overdesign resulting from lack of knowledge of the ground conditions or soil properties. An example is presented in **Box 1**, where the existing pile design was optimised following further site investigation through drilling of deeper boreholes and in-depth geotechnical analysis.

A design can also be optimised by using alternative, innovative foundation types, e.g. by ground improvement, which may allow piles to be removed from the project altogether **(Figure 1)**[10].

Ground improvement solutions generally provide the most cost-effective and environmentally friendly foundation solution when dealing with poor ground. As many of the techniques contain no cement, concrete or steel, the carbon footprint is much less than that of comparable piling schemes.

Reusing existing foundations[11] may also become more a favourable option once ground conditions are known so that the load-carrying capacity of the existing foundations can be confirmed.

**Use of better accuracy in setting out the construction (site presence)**
Having assistance and a site presence from the appointed structural or geotechnical engineer in setting out can help minimise errors by the groundworks contractor in sizing and/or forming foundations. This can help reduce waste (and therefore carbon) on the project. For example lightweight building systems, such as structural insulated panels, could potentially be founded on much narrower trench fill foundations, given accurate setting out of the excavations.

A site-based engineer can also provide immediate support with regards to unexpected ground conditions so that designs can be altered quickly.

**Reappraisal of foundation design with further testing**
When geotechnical recommendations have been made on a project through issue of a geotechnical interpretative report (GIR) and geotechnical design report (GDR), these details are sometimes not revisited later in the project lifetime.

This means that geotechnical recommendations at early RIBA stages are used throughout the lifetime of the project, including for detailed design. This is overly conservative.

We must refine and evolve geotechnical designs throughout a project using appropriately applied factors of safety to counteract the ground variability and uncertainty. This may help to reduce conservatism and therefore increase the sustainability of the project.

This is likely to require further site investigation and monitoring throughout the later stages of the project, the results of which can be used to update the foundation design at these later design stages. Advice from geotechnical engineering specialists should also be sought to determine whether any changes to the original designs are required.

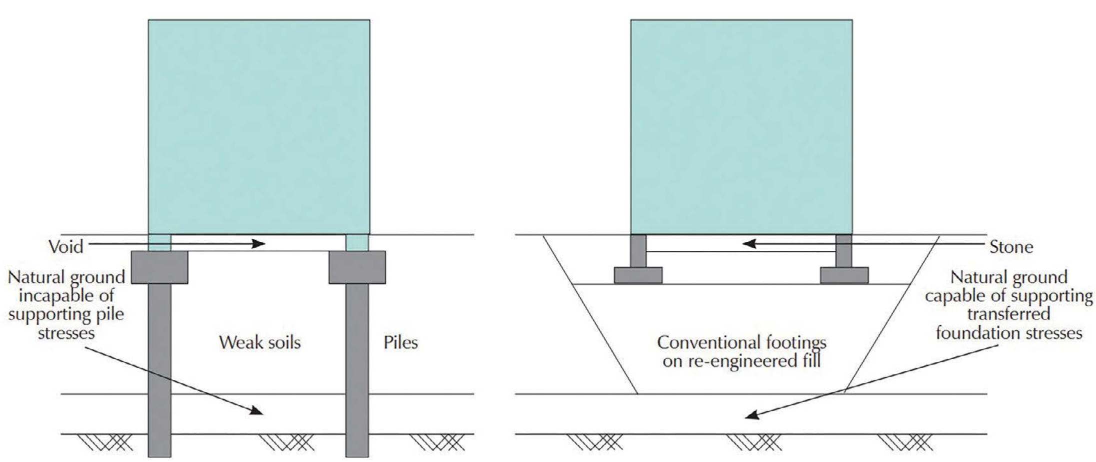




**FIGURE 1:** Representation of system of ground improvement (right) as alternative to piles[10]

### Table 1: Summary of sustainability objectives from selected papers

| | **Long *et al.* (2009)[2]** | **Pantelidou *et al.* (2012)[3]** |
|---|---|---|
| **Sustainability objectives** | (i) Waste management<br>(ii) Infrastructure development and rehabilitation<br>(iii) Construction efficiency and innovation<br>(iv) National security<br>(v) Resource discovery and recovery<br>(vi) Mitigation of natural hazards<br>(vii) Frontier exploration and development | (i) Energy efficiency and carbon reduction<br>(ii) Materials and waste reduction<br>(iii) Maintaining natural water cycle and enhancing natural watershed<br>(iv) Climate change adaptation and resilience<br>v) Effective land use and management<br>(vi) Economic viability and whole-life cost<br>(vii) Positive contribution to society |

**Box 2. The Heights Primary School, Reading**

- Specified use of vibro stone columns (VSC) for scheme as opposed to deep piled foundations.
- VSC designs were reviewed by Curtins to ensure correct parameters used.
- Works were supervised on site to improve accuracy.
- The result was a significant reduction in embodied carbon.

**Use of materials with lower embodied energy**

Consideration of the environmental impact and appropriate specification of the construction materials adopted for geotechnical structures is hugely important in reducing the carbon footprint of a project.

Alternatives to traditional cement and concrete include blended cements and concretes, concretes that store $CO_2$ and cements made from alternative materials. For example, ground granulated blast-furnace slag (GGBS) has been used by major piling contractors as a cement replacement. Note, however, that GGBS and other cement replacements are limited in their usefulness[12,13]. With GGBS, the setting time will usually be extended slightly and it therefore requires coordination with the contractor.

Ground improvement is another key way to eliminate or reduce cement usage in foundation construction. Most consultants consider ground improvement only applicable for light structures and maintain that piled foundations should be used for heavy structures. However, there are some common applications where both solutions are feasible using deep vibro-compaction, vibro-replacement (stone columns; **Box 2**.), wet or deep soil mixing, and jet grouting.

<u>Barriers to adoption</u>

One of the key barriers to advances in geotechnics (be it use of new materials or ground improvement) is the lack of demand. Clients, architects, engineers and contractors are often cautious about using novel building materials, perceiving them as too risky, more costly and more difficult to use. They are wary of changes in a product that has to ensure safety over decades and have a strong preference for a product that is easy to use in most applications without additional training. Finally, they are subject to financial, insurance and legal constraints that shape how innovative they can be.

The solution is likely to be governmental. In its National Infrastructure and Construction Pipeline[14], the UK government has set out how £650bn of private and public investment will be spent over the next 10 years and has already set ambitious requirements for key infrastructure projects with regards to sustainability. For example, the concrete for London's Crossrail (Elizabeth line) project was required to have a minimum cement replacement content of 50%.

If the government could insist that all major developers adopt carbon-intensity targets for their projects, this could trigger profound changes in the market and drive sustainability in the industry.

The process would likely evolve in this direction if the Building Regulations incorporated a requirement to limit embodied carbon emissions in construction, as in the Part Z proposal[15]. The government's Construction Playbook[16] outlines policies around publicly

| | Basu *et al.*[4] and Vaníček *et al.* (2013)[5] | Basu *et al.* (2015)[6] | Taylor (2020)[7] | EFFC (2022)[8] |
|---|---|---|---|---|
| | (i) Use of alternative, environmentally friendly materials in geotechnical constructions, and reuse of waste materials<br>(ii) Innovative and energy-efficient ground improvement techniques<br>(iii) Bio-slope engineering<br>(iv) Efficient use of geosynthetics<br>(v) Sustainable foundation engineering that includes retrofitting and reuse of foundations, and foundations for energy extraction<br>(vi) Use of underground space for beneficial purposes including storage of energy<br>(vii) Mining of shallow and deep geothermal energy<br>(viii) Preservation of geodiversity<br>(ix) Environmental protection including protection of green fields<br>(x) Geohazard mitigation<br>(xi) Incorporation of geo-ethics in practice | (i) Use of alternative, environmentally friendly materials and reuse of waste materials in geotechnical construction<br>(ii) Innovative, environmentally friendly and energy-efficient geotechnical techniques for site investigation, construction, monitoring, retrofitting, ground improvement, and deconstruction<br>(iii) Retrofitting and reuse of foundations and other geotechnical structures<br>(iv) Use and reuse of underground space for beneficial purposes like pedestrian pathways, public transit, and water distribution system, and for storage of energy, carbon dioxide, and waste products<br>(v) Characterisation, analysis, design, monitoring, repairing, and retrofitting techniques in geotechnical engineering that ensure or contribute to reliability (robustness and resistance) and resilience<br>(vi) Geotechnical techniques involved in the discovery and recovery of geological resources like minerals and hydrocarbons, and in exploitation of renewable energy sources, such as shallow and deep geothermal, solar, and wind energies<br>(vii) Geotechnical techniques for pollution control and redevelopment of brown fields and other marginal sites<br>(viii) Mitigation of geohazards (e.g. landslides, earthquakes, and blasts) that also include the effects of global climate change<br>(ix) Environmental and socioeconomic impacts from geo-activities<br>(x) Practice of geo-ethics and geodiversity<br>(xi) Development of sustainability indicators and assessment tools in geotechnical engineering | (i) Retrofitting and reuse of foundations and other geotechnical structures<br>(ii) Improvements to intrusive investigations to enable foundation reuse<br>(iii) Structural movement and/or load monitoring to enable foundation reuse | (i) Reuse of materials, e.g. sheet piles, steel piles, demolition rubble, or existing foundations on brownfield sites<br>(ii) Reducing overconsumption of fuel and materials<br>(iii) Connecting to the electric grid if possible<br>(iv) Reducing waste, following the waste reduction hierarchy<br>(v) Targeting efficiency improvements when replacing or upgrading equipment<br>(vi) Education and awareness, e.g. educate site teams about energy efficiency, designers about whole-life carbon and carbon payback periods<br>(vii) Reducing cement use |

procured construction projects, and includes the requirement to include whole-life carbon assessments within procurement processes. The Greater London Authority also requires whole-life carbon assessments on referable projects in London[17].

Geotechnical engineers should be at the forefront of these changes. The EFFC/DFI Carbon Calculator[18] is a useful tool to compare different geotechnical concepts, designs and use of (alternative) materials to determine the option with the lowest carbon footprint. It is considered to be a useful starting point.

**Reuse of soils on site**

One of the main targets of worldwide environmental policies is to reduce landfilled waste volumes, and one way to achieve this reduction is by reusing waste materials.

A variety of waste products can be utilised in geotechnical constructions[5]. These products can be categorised into industrial wastes (e.g. ash and slag), construction and demolition wastes (e.g. used bricks, concrete and asphalt), mining wastes (mine tailings), and other wastes (e.g. tires, plastics, glass and dredged material).

In addition, naturally occurring soils can often be reused both on and off site, taking into consideration their characteristics and ensuring that these are compatible with the new soil application.

Numerous geotechnical and geo-environmental parameters dictate whether soil can be reused on sites. In some cases, geotechnical improvement and/or geo-environmental treatments are required along with material management plans.

Curtins has the in-house expertise to support material reuse, as detailed in **Box 3 overleaf**.

A detailed Phase One Risk Assessment and


site investigation, followed by competent cut-and-fill analysis and an earthworks specification in accordance with relevant guidance[19,20], is essential to confirm what materials can be reused on site and in what context.

## Conclusions

Geotechnical works can play an important role in moving towards more sustainable building construction practices, in close partnership with structural engineering methods.

This article provides some project-related objectives that can be used by both geotechnical and structural engineers to improve the sustainability of a project. These include increasing the scope of the site investigation, optimised foundation design, improved accuracy in setting out, reappraisal of foundation design, use of materials with lower embodied energy and reuse of soils on site.

It is considered that these objectives can be achieved through a better understanding of sustainable approaches to geotechnical engineering by both geotechnical and structural engineers. This learning and development of engineers will be expedited by new governmental approaches to tackling whole-life carbon emissions in building projects, including the setting of mandatory carbon limits.

### Box 3. Exchange Square, Birmingham (value: £120M)

- An earthworks specification combined with a materials management plan was utilised to allow 11 000m$^3$ of materials to be reused on site.
- Allowed sustainable construction via management of excavated materials which would otherwise have been destined for landfill.
- Reuse of site-won materials saved the client £1.5M.

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