INFORMATION PAPER

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SUSTAINABILITY IN FOUNDATIONS

A review

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There is increasing interest in sustainable development, 'zero-carbon' buildings and use of local, renewable, recycled and low-embodied-energy materials in construction. Cost considerations and ease of construction tend to dictate foundation choice. This may not always result in the most sustainable option. This Information Paper presents a review of the sustainability agenda, details influences on current foundation practice, discusses methodologies for assessing the sustainability of foundations and presents best practice guidance. Although some of the points discussed are relevant to foundations in general, this paper principally deals with the foundations of low-rise buildings, and housing in particular.

Figure 1: Bullivant continuous helical displacement piling system, for improved capacity bored piles without creating spoil, in use on the BRE Innovation Park

INTRODUCTION

The trench fill foundations for a typical semi-detached house comprise around 18 m^3 of concrete, or the equivalent of around 3000 kg of embodied carbon dioxide (CO_2)*. In comparison, the amount of CO_2 sequestered in the processed softwood of a typical timber frame house is around -2500 kg† (ie the net amount of embodied CO_2).

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* Based on data for embodied CO_2 of concrete foundations from *Sustainable concrete: the environmental, social and economic sustainability credentials of concrete*. TCC/05/03. Camberley, The Concrete Centre, 2007.

† Based on data for embodied CO_2 of structural timber from the BRE Environmental Profiles database. This figure is a cradle-to-grave figure, which includes the emissions from energy use throughout the life cycle, 4.4 tonnes of CO_2 that remain sequestered in the timber within the building and the emissions of greenhouse gases from the typical disposal of timber at end of life including landfill. It is a negative number because the amount of CO_2 that remains sequestered within the timber at end of life (ie after 100 years in a landfill) is greater than all the emissions of greenhouse gases throughout the life cycle.

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Depending on ground conditions, various foundation types are available – ranging from the use of concrete rafts to steel or concrete piles. The most cost-effective foundation solution may not necessarily be the one with the least environmental impact. The use of concrete in foundations is occasionally profligate – BRE Report BR 473[1] gives an example where a concrete raft 1.5 m thick was used to support a simple log cabin adjacent to the Thames in Staines.

THE SUSTAINABILITY AGENDA – PROGRAMMES AND OPERATING PRINCIPLES

'Sustainability' is a broad term that refers to the continuation of economic development while leaving suitable resources for future generations and protecting as far as possible natural ecosystems, in a socially acceptable manner. The 1987 Brundtland Report[2] defined sustainable development as 'Development which meets the needs of the present without compromising the ability of future generations to meet their own needs'.

For the ground engineer, a more sustainable foundation might be achieved by measures such as using recycled aggregate, reducing vehicle movements or utilising efficient design. Defining the most sustainable foundation solution is complex. In addition to the embodied impacts associated with extracting and processing materials, and sourcing aspects for the materials used, the impacts of the construction process also need to be considered. The foundation type and its scale are dependent on the ground conditions and other site-specific issues such as the influence on adjacent buildings.

There are several tools available to industry to measure the environmental impacts of construction materials and projects. The most commonly used are:

- *The Green Guide to Specification*[3]
- The BRE Methodology for Environmental Profiles of Construction Products – commonly referred to as the 'Environmental Profiles Methodology'[4]
- The BRE Environmental Assessment Method (BREEAM), www.breeam.org
- The Code for Sustainable Homes[5]
- The Civil Engineering Environmental Quality Assessment and Award scheme (CEEQUAL), www.ceequal.com

The Green Guide to Specification

The Green Guide to Specification[3] aims to provide information on the environmental impacts associated with the extraction, manufacture, transport, use and disposal of building materials in construction. The results are used in BREEAM and in the Code for Sustainable Homes to gain materials credits.

Materials and components are arranged on an elemental basis so that designers and specifiers can compare and select from comparable systems or materials as they compile their specification for the following:

- External walls
- Internal walls
- Separating walls
- Roofs
- Ground floors
- Upper floors
- Separating floors
- Floor finishes
- Windows and curtain walling
- Insulation
- Landscaping

Across these building element categories, *The Green Guide* provides an extensive catalogue of over 1200 building products and constructions. These data are set out using an A+ to E ranking system, where A+ represents the best environmental performance (or least environmental impact), and E the worst environmental performance (or greatest environmental impact). The environmental rankings are based on Life Cycle Assessments (LCAs) using the BRE Environmental Profiles Methodology (see below) and include any maintenance and repair over a 60-year study period.

BRE Environmental Profiles Methodology

The BRE Environmental Profiles Methodology[4] is a standardised method of identifying and assessing the environmental effects associated with building materials over their life cycle, ie extraction, processing, use and maintenance, and eventual disposal. It establishes a set of common rules and guidelines for applying LCA to UK construction products, to produce Environmental Profiles. The profiles provide a means for presenting 'embodied' environmental data to cut through the confusion of claims and counterclaims about the performance of building materials.

Environmental Profiles allow designers to demand reliable and comparable environmental information about competing building materials, and give suppliers the opportunity to present credible environmental information about their products. This means that designers can have confidence in the 'level playing field' status of Environmental Profiles for every material type.

The LCA methodology used for Environmental Profiles has been peer reviewed and complies with International Standard ISO 14040[6] and International Standard ISO 14044[7] – an internationally established approach for analysing the environmental impact of products and processes – together with International Standard ISO 21930[8] for the provision of Environmental Product Declarations for construction products. The system fits well with the ISO 14001[9] environmental management principles. BRE devised the methodology in partnership with the UK government and trade associations from the construction product sector to provide a single, consistent approach for applying LCA to all types of construction products.

Environmental Profiles can be created for construction materials, products and building systems and are presented at discrete life cycle stages. Reporting is commonly made on the basis of a unit mass (eg one tonne of brick) or area (eg 1 m^2 of floor finishing). Manufacturers have the discretion to publish any or all of the profile models they develop in the UK database. The three types of Environmental Profile are:

- Cradle to (factory) gate – Extraction of raw materials, transport and manufacturing
- Cradle to site – As for cradle to gate, plus transport to site and building installation/construction
- Cradle to grave – As for cradle to site, plus repair, replacement, maintenance and refurbishment, plus demolition

Figure 2 shows a representation of the life cycle of a construction product.

The data collected during the life cycle of a construction product are assessed against 13 impact categories according to the BRE Environmental Profiles Methodology:

- Climate change
- Water extraction
- Mineral resource extraction
- Stratospheric ozone depletion
- Human toxicity
- Ecotoxicity to freshwater
- Higher level nuclear waste
- Ecotoxicity to land
- Waste disposal
- Fossil fuel depletion
- Eutrophication
- Photochemical oxidation
- Acidification

The results are expressed using 'ecopoints' per 1 m^2 or per one tonne of product (100 ecopoints is equivalent to the impact of one EU citizen over a year). The more ecopoints a product gets, the worse its impact on the environment. The results obtained for one tonne of manufactured product can then be used along with data for other materials within a specification to obtain a Green Guide rating.

To ensure consistency, a common functional unit is used for each building element and building type to ensure that all options have similar performance. For example, the functional unit for external walls for all building types compared in *The Green Guide* is 1 m^2 of external wall, to satisfy Building Regulations (2006) for England and Wales and to have a U-value of 0.3 W/m^{2}K, and to include all maintenance and replacement over a 60-year study period. This rating can be used for BREEAM and for the Code for Sustainable Homes to obtain materials credits.

BREEAM and the Code for Sustainable Homes

The BRE Environmental Assessment Method (BREEAM) is the most widely used environmental assessment method for buildings in the UK and is increasingly used internationally. The environmental performance of any type of building (new and existing) can be assessed.

Standard schemes exist for common building types (eg offices, schools, hospitals), and less common building types can be assessed against tailored criteria under the Bespoke BREEAM scheme. Buildings outside the UK can also be assessed using BREEAM International. Existing buildings can be assessed using BREEAM In-use. For domestic buildings, BREEAM Ecohomes has now been superseded by the Code for Sustainable Homes[5] in England and Wales. Scotland still uses BREEAM Ecohomes.

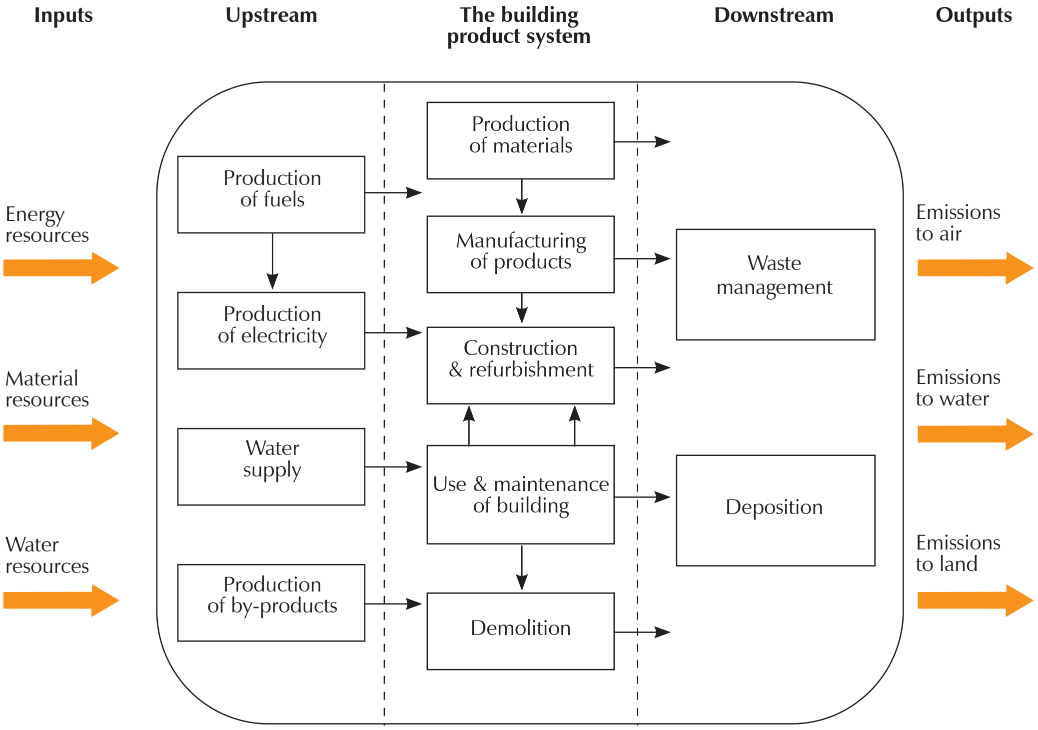

Figure 2: Life cycle analysis of a construction product

On 27 February 2008, the UK government decided that all new homes would have to include a Code for Sustainable Homes certificate within the Home Information Pack from 1 May 2008. The Code for Sustainable Homes uses a rating system of one to six stars to communicate the overall sustainability performance of a new home. The government has also set the ambitious target that all new homes will have to be zero carbon (a mandatory requirement of Code Level 6) by 2016.

In both BREEAM and the Code for Sustainable Homes, buildings are assessed against a number of categories, which vary depending on the type of building assessed. The recurrent ones are:

- Energy
- Water
- Materials
- Surface water run-off
- Pollution
- Health and well-being
- Management
- Ecology
- Transport (BREEAM only)

A large proportion of the credits in both the Code for Sustainable Homes and BREEAM are allocated to the energy performance of the buildings (operational impact) to reflect the relative importance of operational energy in a home built to today's standards. In the code, a maximum of 4.5% of the total available score is currently awarded for minimising the environmental impact of construction products (embodied impact). The embodied impact of building is generally small compared with the operational energy for both existing and new homes built to current standards. However, the government has set a target of 2016 for achieving zero-carbon new homes through revisions to regulation and is debating similar actions for other buildings. As the operational impact of new homes and non-domestic buildings decreases, the relative importance of the embodied impacts of the building will increase. Both BREEAM and the Code for Sustainable Homes will have to be amended to take account of these changes.

Foundations are not assessed in *The Green Guide to Specification* and therefore there are no requirements for the environmental performance of foundations to be evaluated under BREEAM or the Code for Sustainable Homes. The main reason that foundations are excluded from the assessment is due to the link between the most appropriate solution and variations in ground conditions, which results in a wide variation in the types of foundations possible for otherwise similar building designs. Any assessment method would need to cover both house foundation solutions and those for large blocks of flats or mixed-use developments.

CEEQUAL

The Civil Engineering Environmental Quality Assessment and Award scheme (CEEQUAL) was originally developed by the Institution of Civil Engineers (ICE) and is managed jointly by the Construction Industry Research and Information Association (CIRIA) and Crane Environmental. The scheme is supported and promoted by ICE and a group of committed industry organisations such as the Civil Engineering Contractors' Association and the Association for Consultancy and Engineering. The scheme has been developed to encourage the attainment of environmental excellence in civil engineering, and to deliver improved environmental and social performance in project specification, design and construction.

CEEQUAL assesses performance across 12 areas of environmental and social concern. It also provides a checklist of appropriate action for project teams. The scheme uses a points-based scoring assessment that is applicable to any civil engineering or public realm project. CEEQUAL includes environmental and social aspects such as the use of water, energy and land, impacts on ecology, landscape, neighbours and archaeology, as well as waste management, community relations and amenity value.

Several of the CEEQUAL assessment questions are relevant to foundations, such as those covering responsible sourcing of materials, use of local materials, volume of excavated material reused on the site, and carbon emission reduction. As with BREEAM and the Code for Sustainable Homes, there are no credits relating to the actual embodied environmental impact of foundations.

Assessing the environmental impact of foundations

In the absence of Green Guide ratings or any alternative mechanism for assessment, the only requirements for the environmental performance of foundations under BREEAM or the Code for Sustainable Homes relate to the responsible sourcing of materials. There are credits within the Code for Sustainable Homes that are available for the specification of ground floors with low embodied impact using Green Guide ratings.

At present, as BREEAM covers all types of buildings other than housing, it is currently too complex a task to consider the development of a methodology for the assessment of foundations. The Code for Sustainable Homes may also be used in high-rise or mixed-use developments where similar issues arise.

For low-rise domestic buildings, a methodology to assess and quantify the environmental impact of foundations could be based on two parts: a good practice guidance document and a calculator tool based on the methodology underlying BRE Environmental Profiles and *The Green Guide*. Such a methodology would need to consider the different foundation systems required for differing ground conditions to ensure that foundations on poor soil are not discriminated against. An alternative methodology might also involve a scoring system based on improvement over a standard foundation solution. The difficulty in this approach is defining the standard foundation solution.

As the foundation may be integral with the ground floor construction, a 'like-for-like' assessment of the combined impact of the ground floor and foundations may be more appropriate. This would result in the need to consider a large number of possible combinations of foundations and slabs to cater for the range of potential solutions, and also involve consideration of the layout and support for loading such as external walls, roof and internal partitions. Such an evaluation could be based on a comparison of the environmental impact of substructure from the top of the floor or the foot of the walls downwards. This approach would also be logical for a cost comparison, and would be valid when comparing the use of trench fill with shallow footings combined with foundation blockwork. This does not preclude a separate environmental assessment of directly comparable foundations such as different types of piles, or different pile configurations, but some consideration of the possible variation in the connection to the superstructure would be appropriate.

FOUNDATION PRACTICE

Function and types of foundation

The functions of foundations are to transfer building loads to the ground while limiting settlement and to provide stability to the building, eg against wind loads. Excessive settlement, and in particular excessive differential settlement between parts of the building, can give rise to problems such as cracking of brickwork and internal linings (especially around openings), sticking of doors and windows and breakage in services such as sewers. Such problems can be extremely expensive to rectify, and may ultimately involve remedial foundation work such as underpinning.

The main types of foundation for buildings include:

- Strip footings
- Trench fill
- Raft
- Pad
- Displacement piles (driven precast concrete, steel and timber, also driven cast-in-place types)
- Replacement or bored piles (in-situ concrete)

Other techniques for increasing the capacity of the ground, ie 'ground improvement', include soil mixing, installation of vibro-stone columns, compaction and replacement with engineered fill.

Influence of ground conditions

Foundation type is largely dictated by ground conditions. As might be expected, these vary considerably in the UK, the geological history of which is dominated by successive periods of sedimentation under varying conditions ranging from lake to deep ocean, followed by erosion by glacial and river action. To complicate matters further, this eroded sedimentary platform has been buckled by continental drift and overlain by alluvial material as sea levels have changed during successive periods of glaciation. Thus the soil types range from soft rock such as chalk to sands, gravels, clays and peat. For example, the geological succession in the south-east of England comprises – with some generalisation – Devonian limestones overlain by the Oxford and Kimmeridge clay formations, Portland and Purbeck limestone, Weald Clay, Gault Clay, Lower Greensand, chalk, Upper Greensand, Lambeth Group/Woolwich and Reading Beds (sand and clays), London Clay, Bagshot sand, river terrace deposits and alluvium. On the Isle of Wight and Isle of Purbeck, much of this succession can be encountered on the surface within a few miles.

In hilly areas such as the South Downs and Chilterns, buildings may be founded directly on chalk or deposits formed from weathered rock, eg head or clay with flints. Hazardous or difficult ground conditions may be encountered in some areas due to voids such as sink holes. Some strata such as certain forms of oolite (a type of limestone) are notoriously waterlogged and unstable. Traditionally, areas of poor, marshy ground tend not to have been developed for housing – but may be developed in the future. Areas of soft ground in the UK include the floodplain deposits of the lower Thames, Severn, Forth and Clyde rivers, the Fens and Broads in East Anglia and the Somerset levels. Softer alluvial clays in river flood plains and esturine areas tend to be associated with a desiccated crust that may provide sufficient bearing for a raft foundation, as an alternative to piles. In the case of the raft foundation, the foundation also comprises the ground floor.

In some areas of the country, foundation choice is determined by the risk of subsidence from mining activity. For example, collapse of old limestone mines is a problem in parts of the West Midlands. In these areas, raft foundations are used to limit the effects of settlement. Other ground hazards that may warrant more extensive foundations include old wells, or the need to bridge over a large sewer or culvert. Increasingly, more marginal land with difficult ground conditions is being developed, including brownfield sites. Contamination on an old industrial site may comprise anything from the presence of tar pits to a layer of kerosene floating on the groundwater. For a site such as an old quarry or a former opencast mine, options for the foundations may include piling through to the bedrock or compaction of the fill. Particularly for contaminated land, it may even be expedient to remove the soil entirely and replace it with clean material. The nature of the fill may vary from well-graded rock spoil to domestic waste, but it is invariably in an uncompacted condition. Building on uncompacted fill presents particular geotechnical difficulties, including the risk of collapse compression[10]. Improving the bearing capacity of fill or reducing the risk of collapse compression by surcharging usually involves the placement of many thousands of cubic metres of soil (Figure 3). For deep-fill sites, this is usually only viable by using locally won material due to transport costs.

Much of the UK is covered by firm to stiff clays. Over the southern half of England, many of these are termed 'shrinkable', ie they are subject to volume change on change in moisture content (Figure 4). In contrast, the chalky or sandy glacial tills of East Anglia

Figure 3: Surcharging fill to reduce the risk of collapse compression

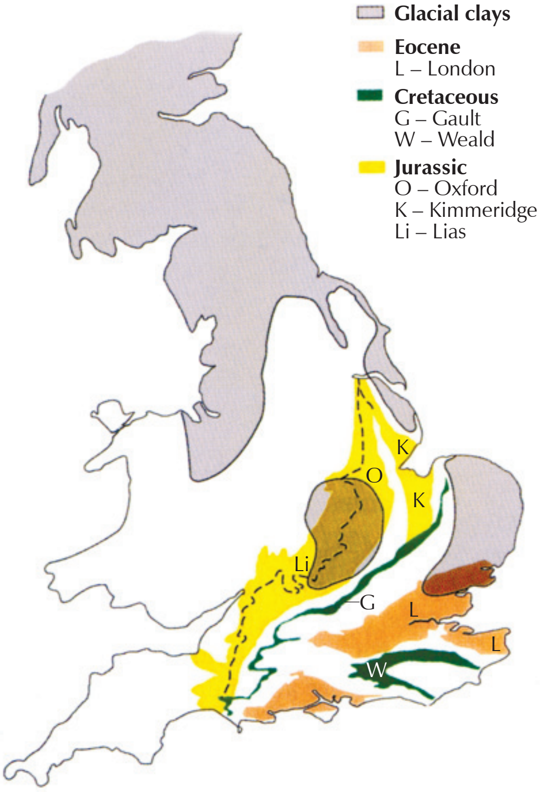

Figure 4: Distribution of shrinkable clays in the UK

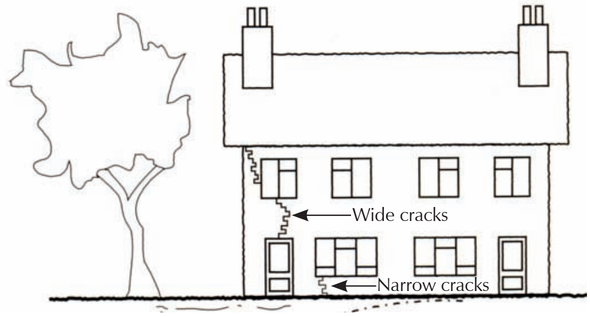

Figure 5: Damage caused by dessication of clay soil by trees

Figure 6: Extensive damage to a building with shallow trench fill foundations, caused by tree-related subsidence

and Northern England have relatively low volume change potential. For low-rise buildings on firm to stiff clays such as London Clay, Gault Clay (around Cambridge) and Oxford Clay, trench fill or strip foundations are the norm. Minimum depths for these are defined by NHBC guidance[11], with depths largely based on the need to avoid seasonal movement due to desiccation caused by trees (Figure 5). A failure to provide sufficiently deep foundations in such circumstances can lead to severe damage to buildings (Figure 6), resulting in the need for underpinning. The possibility of a greater frequency of extreme weather events such as droughts due to climate change, or increased planting of trees in close proximity to housing, may result in the need for more substantial foundations for buildings. Piles are increasingly being used in conjunction with ground beams as an alternative to trench fill or strip foundations, in particular with off-site panellised construction. Nevertheless, there are probably many instances when excessively deep trench fill foundations are constructed in preference to contracting in specialist piling services. The depth of trench fill foundations can range from 0.9 m to 3.0 m depending on clay type, tree species and proximity – potentially a three-fold increase in the amount of concrete required. Piles tend to be an economic alternative, overall, when trench fill exceeds a depth of 2.5 m. Such piles are normally taken to a depth of at least 6 m.

In terms of assessing the sustainability of these alternatives, it needs to be borne in mind that piles are normally used in conjunction with a reinforced concrete ground beam, whereas trench fill may be built on directly. Some proprietary piled foundation/ground floor systems exist that efficiently provide both the ground floor slab and perimeter beams for the walls, together with the required level of insulation (Figure 7). In addition to ground floor systems supported on piles, there are semi-rigid systems designed to act as rafts. Suspended timber ground floors, and concrete ground floors that bear directly on the soil, are now comparatively rare, having been largely superseded by beam and block suspended concrete floors.

Figure 7: Proprietary foundation system comprising insulated ground floor slab and reinforced concrete perimeter beam, supported on piles

Foundation loading and efficiency

For domestic buildings, the weight of the structure may have limited influence on the design of trench fill or strip foundations. For a timber frame house clad in timber weatherboards, foundation loads are around 10–20 kN/m run, whereas for brick-clad timber frame the foundation loads are in the region of 20–35 kN/m run. In comparison, foundation loads for a brick and block house are around 40 kN/m run. However, this may not necessarily result in less substantial or cheaper foundations being required for the lighter structure. The depth of the foundations is often governed by the need to avoid the effects of desiccation caused by trees. In many instances, clay soils are encountered that are classified as 'firm', for which 450 mm wide foundations are usually adequate for both brick and block, and timber frame. Although narrower foundation widths are possible on compact sandy soils or stiff clay in order to provide the necessary geotechnical capacity, these may restrict working space or require much greater accuracy in setting out the construction.

Where ground conditions are softer, and as building heights increase, the benefits of lower weight building materials may result in a reduced number or size of piles, and reduction in the thickness and reinforcement of ground beams and rafts. Panellised building systems such as structural insulated panels, combined with lightweight direct cladding such as timber weatherboarding or render, could potentially be founded on much narrower trench fill, given accurate setting out of the excavations. According to Bown[12], the foundations and ground floor, combined, account for 34% of the environmental impact of a typical masonry building. As building practice moves to more lightweight cladding and wall systems, the impact of foundations on the sustainability of construction is likely to be higher.

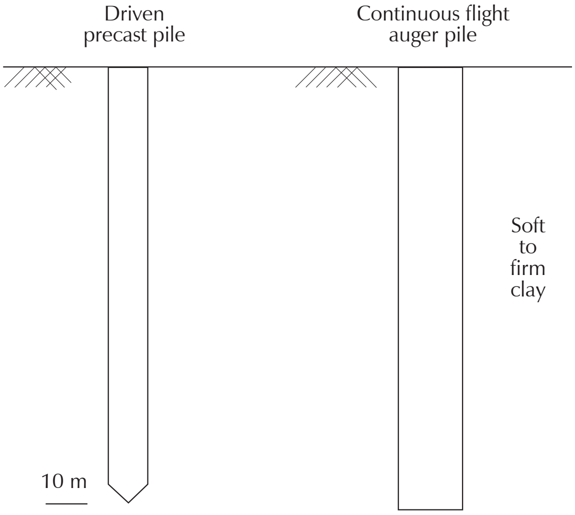

Figure 8: Piles with identical working loads

In terms of effectiveness in mobilising shaft friction displacement, driven precast concrete or steel piles are more efficient than replacement cast-in-place piles because the action of inserting the pile increases lateral pressure and consolidates the soil. The opposite may be the case for replacement piles. For cast-in-place piles, shaft friction may be increased by forming the pile in the shape of a helical screw (Figure 1), while end bearing can be increased by under-reaming. Taper also increases shaft capacity, eg in the case of log pole timber piles and some specially formed steel tube piles. Other innovative foundation systems include the use of sheet piles, screw piles and base-driven thin shell piles. Other options for foundations include ground improvement through compaction, grout injection or use of vibro-stone columns. Thus considerable variation and choice is present in the field of foundation engineering.

For a site comprising soft to firm clay soil, identical working loads of 110 kN per pile can be achieved from either a cast-in-place concrete continuous flight auger (CFA) pile of 300 mm diameter, or a driven precast pile 200 mm square (Figure 8), both being 10 m long. Typically for a lightly loaded pile in such conditions, the amount of steel reinforcement in both cases is the same. The higher strength of concrete required for the driven pile tends to counteract the greater volume of concrete used for the CFA pile, with the CO_2 cost of the concrete for the driven pile being 177 kg, versus 230 kg for the CFA pile‡. The steel reinforcement adds a further 83 kg of CO_2 to the environmental cost of each type of pile. In the case of the CFA pile, there may be spoil to dispose of, whereas for the driven pile additional transport costs in terms of distance travelled are likely. Another option would be to use recycled steel pipe from ex-oil exploration stock, but again the environmental impact of transport would likely be significant due to more limited availability. Driven piles may not be suitable for all sites; in particular, their use may cause problems such as ground heave, while performance of CFA piles can be improved by using casing, which avoids removal of excess soil from around the bore.

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‡ Based on data for embodied CO_2 from the BRE Environmental Profiles database.

Other considerations

Apart from building loads, soil type and the presence of trees, other factors may influence the choice of foundations. These include:

- Constraints on noise and vibration during installation (eg pile driving)
- Site space and traffic management issues
- Site safety (eg bricklaying in excavations)
- Transport and other logistical problems
- Project timeline
- Groundwater conditions
- Building on slopes
- Form and shape of the building
- Adjacent structures, including tunnels
- Building function (eg basements)
- Local availability of materials such as fill, aggregate and reclaimed steel
- Presence of contaminated land
- Presence of archaeology
- Presence of foundations from a previous building

The build sequence can have a direct effect on the environmental impact of the construction. For large projects involving basement construction, the use of temporary props or use of the floor slab to act as horizontal frames can result in reduction in the required capacity of the contiguous piling forming the retaining walls (eg pile size and amount of steel reinforcement), which would otherwise have to act as cantilevers to support the excavation. However, this form of propped wall basement construction has the disadvantage of restricting the working area[13].

Value engineering and innovation

Consideration for the environment is one of the key principles fostered by ICE. For major projects, consideration is often given to the sustainability of foundations, with contractors sending a carbon bill of quantities with their tender. More carbon-friendly foundation systems can be used to reduce the carbon footprint of the foundation element of the project, when appropriate. For major projects, the clients often demand sustainability in all aspects of the project. Unfortunately, even for some environmentally focused projects, the environmental costs of the foundations are not considered (see case study 1). The use of foundation testing to prove designs, consideration of alternative methods and use of innovative techniques can result in foundations with lower cost and potentially lower environmental impact (see case studies 2 to 6). An environmental assessment of any alternative foundation solutions would need to take into account the embodied energy of the materials used (eg lime, cement, steel), together with the energy use of the plant involved, as well as other transport impacts and the possibility of reuse and recycling.

For simple foundations and small projects such as housing, the foundations are often specified and installed on considerations of cost alone, and without any consideration for sustainability. Design input by the superstructure designer is usually restricted to loads and their spacing on the foundation. The actual detailed design of the foundation is left to the foundation specialist and the construction techniques he has available to him. The ‘groundworker’ will construct the foundations to be acceptable to the Local Authority building control officer or an approved inspector who will certify the works.

Case study 1 – Overdesign of foundations

Lightly loaded driven piles were required for a recreational structure. Large-diameter new steel piles were specified, but could not be driven through a layer of dense sand and gravel, resulting in wastage of around 50% of the material. When tested, the piles were found to have a factor of safety of 7 (ie much higher capacity than required). Better knowledge of the ground conditions, and the use of alternative recycled steel piles of smaller diameter, might have led to foundations with lower environmental cost.

Case study 2 – Benefits of foundation testing

For a housing estate in Hull with ground conditions consisting of fill and soft to firm clay over chalk at a depth of 20 m, initial soils data suggested the use of long bearing piles. By carrying out a series of load tests on piles of different lengths, it was possible to back-analyse appropriate shaft resistance and base area resistance values for the clay, resulting in the use of much shorter piles.

Case study 3 – Alternative designs

For a multi-storey construction in south-west London, the foundation scheme indicated the need for piled foundations supporting tension loads, with the ground floor slab also supported on augered piles. An alternative design was formulated based on a re-examination of soils data. The use of permanently cased base-driven piles on the building perimeter, in combination with stone columns using material available on site, resulted in a reduction in the size of the slab and the total number of piles.

Case study 4 – Innovative foundations

Removable steel screw piles of 6 m length were used to support modular buildings on a site occupied by large trees (figures 9 and 10), to avoid the effects of seasonal desiccation of clay and minimise root damage. This avoided the permanent installation of concrete piles, and will allow the site to be restored to its original condition when the modular buildings are removed.

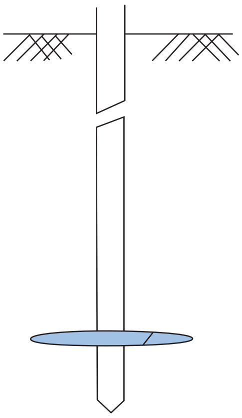

Figure 9: Screw pile (conceptual)

Figure 10: Modular buildings supported on screw piles, near to trees
Courtesy of ScrewFast Foundations Ltd

Case study 5 – Ground improvement through soil mixing
For construction of a road across marshland on the Norfolk coast comprising soft peat and silt layers overlying medium-dense sand, deep soil mixing was employed. This avoided groundwater problems and the reduced vehicle movements associated with the original proposal, which was to increase bearing capacity by the removal of the weak soils and replacement with engineered fill. The soil mixing technique involves the use of an excavator with a mixing head (Figure 11) together with cement or lime injection. A triple auger mixing system (Figure 12) may be used to obtain greater depths. This technique can also be used as an alternative to piling.

Case study 6 – Ground improvement through compaction
As an alternative to piled foundations, a proprietary system of ground improvement involving roller dynamic compaction of lime-treated fill (figures 13 and 14) was used to control settlement and allow shallow trench foundations to be used for houses built on an old quarry.

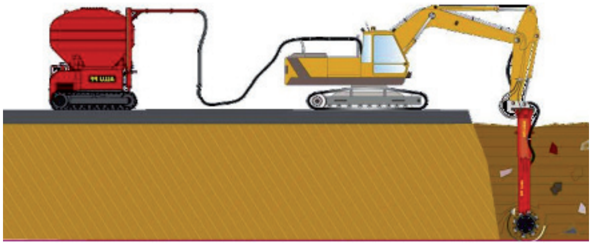

Figure 11: Soil mixing
Courtesy of Eco Foundations

Figure 12: Triple auger soil mixing system
Courtesy of Eco Foundations

Figure 13: Roller dynamic compaction
Courtesy of Con-form

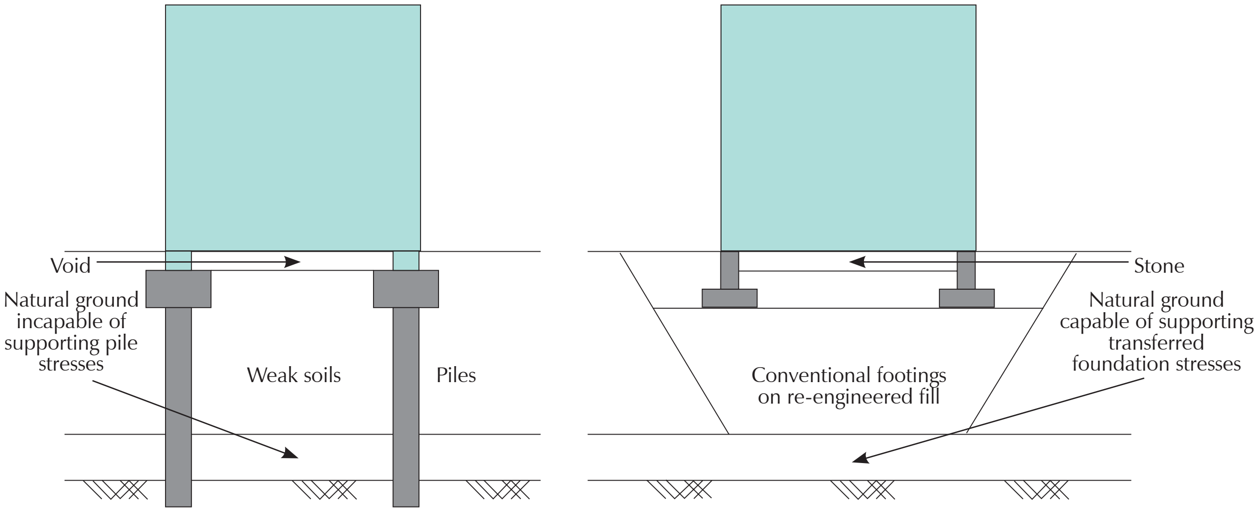

Figure 14: Representation of proprietary system of ground improvement (right) as an alternative to piles
Courtesy of Con-form

A best practice approach

Although choice of materials for the components of buildings above ground may often be determined by preference for more sustainable materials using *The Green Guide*, foundation design and construction is often executed as a separate process. The foundation engineer is constrained by ground conditions and the form and loading of the building, with a relatively limited choice of materials usually limited to cast-in-place concrete, precast concrete or driven steel piles. Foundation choice is more likely to be driven by cost considerations, which may not always result in the lowest environmental impact. Above-ground materials may also be selected on the basis of architectural choice, whereas for foundations the more sustainable option would in many cases be attained through increased efficiency of design and reduction in the use of virgin material.

Preferably, the environmental cost of the foundations should be known, and conveyed to the building designer at an early stage so that this can be mitigated by changes – where possible and practical – to the location of the building, the form and type of foundation and by use of lower embodied-energy materials, eg cement replacements. As a basis for the assessment of the impact of foundations, information on materials could be based on *The Green Guide to Specification*.

For a given building type and ground condition, the efficiency of the foundations may be calculated in terms of the ratio of environmental cost to load carried, or for a standard house in terms of ecopoints per unit of floor area. Thus, a single-storey building developed close to trees with deep trench foundations may score more poorly than a two-storey building on piles. Such information might usefully be conveyed to the building designer.

A best practice approach to more sustainable foundations could be based on the following:

- Optimising foundations through good site investigation and avoiding overdesign resulting from lack of knowledge of the ground conditions or soil properties
- Considering alternative, innovative foundation types such as screw piles and tapered piles
- Using better accuracy in setting out to minimise the size of foundations
- Minimising the impact of trees on foundations, eg by avoidance or other mitigation such as root barriers
- Optimising the form of the building (eg plan, layout, requirements for stability) to minimise foundations
- Minimising waste during the construction phase
- Reducing or eliminating spoil removal from the site, eg by using driven piles or by balancing excavation with areas of fill
- Ensuring any material that has to be removed from site is recycled rather than landfilled where possible
- Using foundation testing to enable a reduction in the extent of foundations while maintaining performance
- Using low-embodied-energy, secondary or recycled materials in foundation construction, eg cement replacements such as pulverised fuel ash or ground granulated blastfurnace slag
- Reusing existing foundations (see *Reuse of foundations for urban sites: a best practice handbook*[14] and *Reuse of foundations*[15])
- Using foundations as part of energy storage and production systems
- Incorporating 'buoyant' foundation design as a function of the building, eg basements
- Decoupling extensions, reducing the need for provision against differential movement
- Incorporating provision for greater settlement, eg flexible services
- Reducing load on the foundations through use of lightweight materials in the superstructure
- Ensuring that the foundations, ground floor slab and structure are designed in an integrated manner to ensure the most sustainable overall result
- Reducing the broader environmental impact of foundation works (ie consideration for ecology, habitat disturbance) or reducing impacts on neighbours resulting from construction activities

With development of a scoring system, such a methodology or checklist could be used alongside *The Green Guide to Specification*.

CONCLUSIONS

Cost considerations and ease of construction tend to dictate foundation choice. This may not always result in the most sustainable option. Foundation failures are extremely expensive and difficult to rectify, and not surprisingly there is considerable aversion to risk. This can lead to overconservative designs.

Civil and geotechnical engineers can, and do, offer more sustainable options for foundation construction. Foundations are often integral to the ground floor construction, and this aspect, together with variation in ground conditions, may need to be taken into account in any assessment system.

Where building practice for housing results in the use of more lightweight cladding and wall systems, or greater use of renewable materials such as timber, the impact of foundations on the sustainability of construction is likely to increase.

More sustainable foundations can be achieved with measures such as:

- Better practice in site investigation and project planning
- Optimised foundation design
- Use of better accuracy in setting out the construction
- Reappraisal of foundation design with testing
- Use of materials with lower embodied energy

Building designers should consult with the project's geotechnical engineer at an early stage in the construction sequence – preferably at the initial design stage – so that the environmental impact of foundation construction can be minimised.

REFERENCES

[1] Charles J A. Geotechnics for building professionals. BRE Report BR 473. Bracknell, IHS BRE Press, 2005.

[2] Brundtland G (ed). Our common future: the world commission on environment and development (Brundtland Report). Oxford, Oxford University Press, 1987, p. 24. Available at: www.un-documents.net/wced-ocf.htm

[3] Anderson J, Shiers D E and Steele K. The green guide to specification. BRE Report BR 501. Bracknell, IHS BRE Press & Oxford, Wiley-Blackwell, 2009, 4th edition.

[4] BRE Global. Methodology for environmental profiles of construction products: product category rules for type III environmental product declaration of construction products. Garston, BRE Global, 2007. Available at: www.thegreenguide.org.uk (Background to the Green Guide > Methodology).

[5] Communities and Local Government. Code for Sustainable Homes. Technical guide. Version 2, May 2009. London, RIBA Publishing, 2009. Available at: www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf

[6] British Standards Institution (BSI). Environmental management – Life cycle assessment – Principles and framework. British Standard BS EN ISO 14040:2006. London, BSI, 2006.

[7] British Standards Institution (BSI). Environmental management – Life cycle assessment – Requirements and guidelines. British Standard BS EN ISO 14044:2006. London, BSI, 2006.

[8] British Standards Institution (BSI). Sustainability in building construction – Environmental declaration of building products. British Standard BS ISO 21930:2007. London, BSI, 2007.

[9] British Standards Institution (BSI). Environmental management systems. British Standard BS EN ISO 14001. London, BSI.

[10] Charles J A and Watts K S. The assessment of the collapse potential of fills and its significance for building on fill. Proceedings of the Institution of Civil Engineers – Geotechnical Engineering. 1996, 119 (1) 15–28.

[11] National House Building Council (NHBC). NHBC standards 2008, chapter 4.2 – building near trees. Amersham, NHBC, 2008.

[12] Bown A. Whole life performance of clay brick masonry. PhD Thesis. Leeds, Leeds Metropolitan University, 2007.

[13] Gaba A R, Simpson B, Powrie W and Beadman D R. Embedded retaining walls – guidance for economic design. C580. London, CIRIA, 2003.

[14] Butcher A P, Powell J J M and Skinner H D (eds). Reuse of foundations for urban sites: a best practice handbook. EP 75. Bracknell, IHS BRE Press, 2006.

[15] Chapman T, Anderson S and Windle J. Reuse of foundations. C653. London, CIRIA, 2007.

FURTHER READING

[1] Atkinson C, Yates A and Wyatt M. Sustainability in the built environment: an introduction to its definition and measurement. BRE Report BR 502. Bracknell, IHS BRE Press, 2009.

[2] Hammond G and Jones C. Inventory of carbon and energy (ICE). Version 1.6a. Bath, University of Bath, 2008.

[3] Anderson J, Clift M, Bourke K and Lockie S. Performance and service life in the Environmental Profiles Methodology and Green Guide to Specification. Information Paper IP 1/09. Bracknell, IHS BRE Press, 2009.

[4] Lockie S. Building a better future. New Civil Engineer. 1 October 2009, pp. 26–27.

[5] Brownhill D and Rao S. A sustainability checklist for developers: a common framework for developers and local authorities. BRE Report BR 436. Bracknell, IHS BRE Press, 2002.

[6] NHBC Foundation. Efficient design of piled foundations for low-rise housing: design guide. NF21. Bracknell, IHS BRE Press, 2010.

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