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Briefing Paper

The challenge of measuring and mitigating the environmental performance of foundations and substructures

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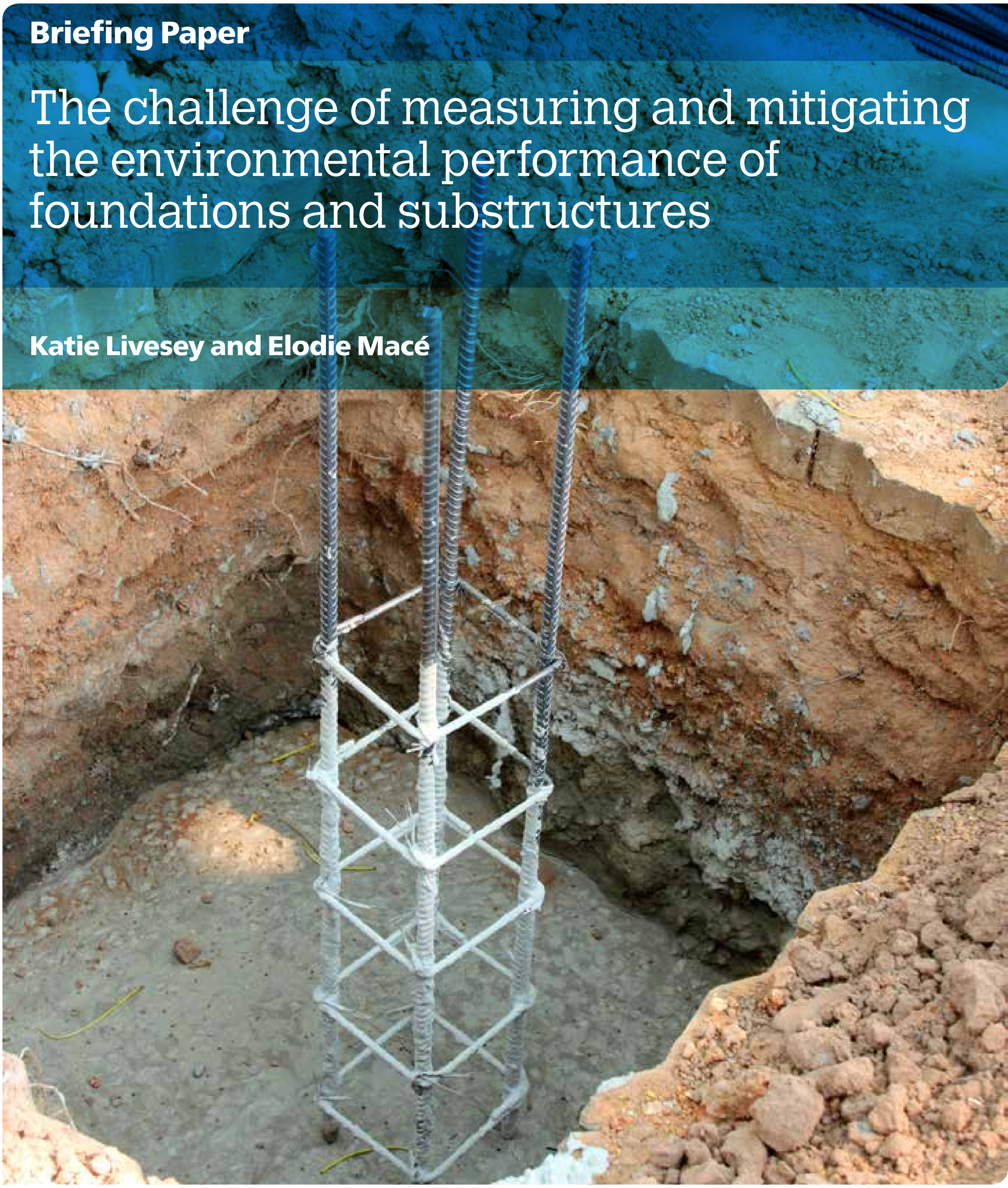

Summary

Challenges related to site-specific ground conditions have traditionally made a consistent and reliable measurement of the environmental performance of foundations and substructures difficult if not impossible. As a result foundations and substructures have tended not to feature in environmental impact assessments for whole buildings such as BREEAM. The new IMPACT methodology has changed this situation and presents the building designer with a building specific solution for assessing the embodied impacts for different foundation and substructure options.

This paper, funded by BRE Trust, highlights relevant issues in the environmental performance of foundations and substructures and is aimed at designers, specifiers and other stakeholders.

BRE Trust

BRE Trust is the largest UK charity dedicated to research and education in the built environment. It was set up to advance knowledge, innovation and communication for public benefit. The Trust uses all profits made by the BRE Group to fund new research and education programmes and to promote its charitable objectives.

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Introduction

The environmental performance of buildings is becoming an increasingly familiar subject to construction professionals, owing largely to the rigour and reach of assessment methods such as BREEAM (BRE Environmental Assessment Methodology). BREEAM is the world's foremost environmental assessment methodology and rating system for buildings, with 425,000 buildings with certified BREEAM assessment ratings and two million registered for assessment since it was first launched in 1990.

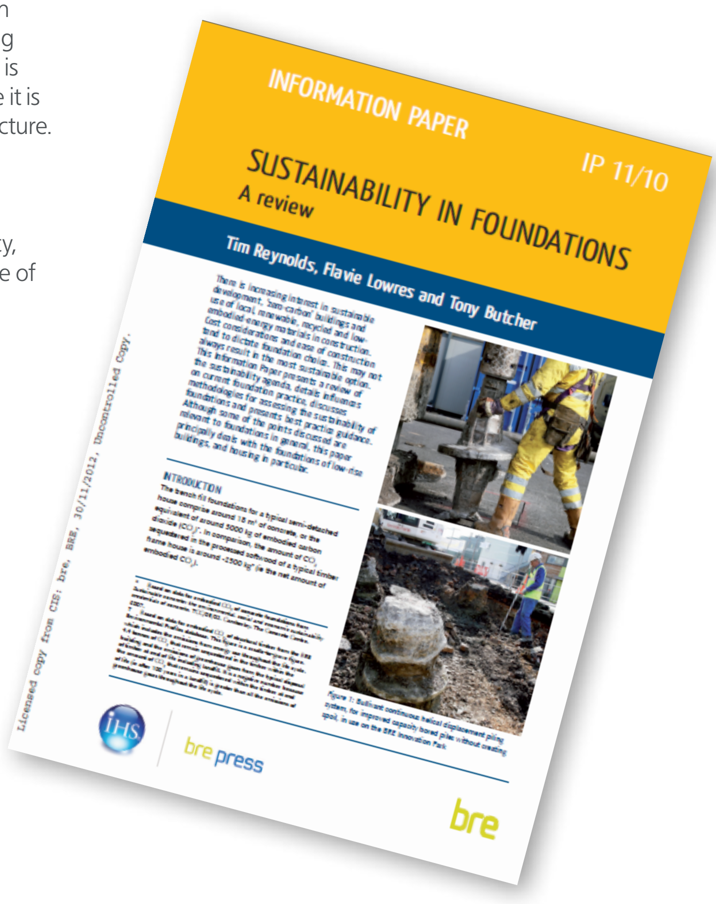
To be more accurate, however, it is the performance of the buildings above their foundations and substructures – that of the superstructures – which is well understood. The performance of the foundations and substructures themselves is less well understood in comparison.

Foundations and substructures have so far received little attention with regard to their environmental performance, mainly because this can be difficult to measure or calculate, as it will typically vary depending on a building's site, its size and its intended use. The superstructure is less affected by ground related site-specific factors, in part because it is isolated from the building's underlying environment by the substructure.

The site-specific factors applying to foundations and substructures include underlying geology and hydrology, ground conditions and ground improvement works. Partly due to this additional complexity, there is a lack of reliable data about the environmental performance of foundations.

Nonetheless, the contribution of a building's foundations and substructures to its overall impact on the environment is likely to be considerable. BRE Information Paper IP11/10, *Sustainability in Foundations*, suggests that the foundations and substructures account for 34% of the environmental impact of a typical masonry building. As the environmental performance of the other components of buildings improves, so the foundations and substructures will make a proportionally greater contribution to the overall environmental impact.

BRE has been exploring the challenge of how to include foundations and substructures in building level environmental impact assessment methodologies. This work has been carried out with the participation of the ground engineering industry.



BREEAM

BREEAM (the Building Research Establishment Environmental Assessment Methodology) is one of the most commonly applied methodologies for assessing the sustainability of buildings. At a 'materials' level BREEAM typically employs 'The BRE Green Guide to Specification' based approach to assessing and comparing the impact of elements used in its construction. Given that a prerequisite for the inclusion of a building element within the Green Guide is that it must be a part of the building where 'the designer or specifier has the opportunity to make a significant difference to the embodied environmental impact of the building', the inclusion of foundations and substructures in the guide is potentially a valuable addition but has always presented a challenge as consistent, reliable and therefore comparable functional units are yet to be successfully created.

BREEAM (BRE Environmental Assessment Methodology)

BREEAM is the leading and most widely used environmental assessment methodology for buildings and communities. It sets the standard for best practice in sustainable design and has become the *de facto* measure used to describe a building's environmental performance.

Who uses BREEAM?
Clients, planners, development agencies, funders and developers use BREEAM to specify the sustainability performance of their buildings. As the *de facto* standard, BREEAM provides a common language and replicable process that allows for speedy and cost effective application by these stakeholders.

Property agents use it to promote the environmental credentials and benefits of a building to potential purchasers and tenants.

Architects and design teams use it to improve the performance of their buildings and their own experience and knowledge of environmental aspects of sustainability.

Building managers use it to reduce running costs, measure and improve the performance of buildings, develop action plans and monitor and report performance at both the single building and portfolio level.

How does it work?
Credits are awarded according to performance in different categories such as Energy, Waste or Materials. To give a whole building assessment of environmental performance, the credits are added together, giving a final score on a scale of Pass, Good, Very Good, Excellent and Outstanding.

Materials category
Points are awarded on the basis of the Green Guide ratings for each building element, and then summed and converted into a number of credits.

Building elements currently assessed under this methodology are external walls, windows, roof, upper floor slabs, internal walls and floor finishes.

The Green Guide to Specification

BRE has worked with the UK construction industry to generate generic life cycle assessment (LCA) datasets for over 400 construction products, using the BRE Environmental Profiles 2008 methodology. These LCA datasets have been used to create generic building element specifications for a range of building types across their life cycle (BRE uses a sixty-year study period, allowing for replacements and maintenance). Elements performing the same functions have been compared using their BRE Ecopoints score, and a benchmark rating scale of A+ to E has been derived. These are known as Green Guide ratings and are presented in the *Green Guide to Specification*. An up-to-date version of the Green Guide is available online on BRE's website, www.thegreenguide.org.uk.

Ecopoints
The environmental impact of construction products, using defined functional units, can be obtained from a life cycle assessment (LCA) study carried out using the BRE Environmental Profiles 2008 methodology, representing the impacts of the studied material or system in 13 different impact categories. The results obtained from the LCA study in these 13 categories are normalized and then weighted according to their perceived importance, to give the Ecopoint score.

The environmental impact of 1 European citizen per year equates to 100 BRE Ecopoints.

This overall Ecopoint score obtained for each construction product is a simplified output of the LCA study that enables the comparison of different construction products in use.

Within the context of the current approaches used to measure and assess the embodied impacts of materials within BREEAM, the following sections explore in Part 1 what the environmental impacts of substructures and foundations are; Part 2 how these impacts may be mitigated and finally in Part 3 how progress may be made in the process of measuring and then selecting the most appropriate solutions.

Part 1 The environmental impact of foundations and substructures

The impacts of foundations and substructures

In the report 'Sustainable Geotechnics', a chapter in the 'ICE Manual of Geotechnical Engineering' (2012), the authors identify four environmental objectives for civil engineering and geotechnics:

- Energy efficiency and carbon reduction
- Materials and waste reduction
- Maintained natural water cycle and enhanced aquatic environment
- Effective land use and management

1.1 Energy efficiency and carbon reduction

Energy efficiency and carbon reduction are major elements in mitigating the impact of buildings and have to be considered over the entire life cycle of construction products. Embodied energy and embodied carbon are the two most commonly used indicators for quantifying the environmental impact of a building element.

Embodied energy and carbon

Embodied energy is the total primary energy consumed by a product during its lifetime. It encompasses the energy required to produce the product, from the extraction of raw materials through to product manufacture, the use and maintenance of the product, and its decommissioning and disposal at the end of life.

Embodied carbon is akin to embodied energy, the only difference being that rather than energy, this is a measure of the total carbon dioxide (CO_2) emissions of a product during its lifetime. It also takes into consideration any related CO_2 uptake (e.g. sequestration by bio-based materials or reabsorption by lime-based materials).

Until recently, the embodied impact of housing has been a peripheral issue for the scientific community, owing in part to the difficulty of analysing it, and in part to the perception that it is unimportant in comparison with operational CO_2. Studies dating from 2008 have estimated the split between the two in new houses to be 20% embodied (installation) and 80% operational carbon. But operational emissions are forecast to fall radically in the next few years as the energy efficiency of buildings continues to improve, and so the embodied CO_2 emissions of buildings will become increasingly important in terms of their contribution to the overall CO_2 emissions of new buildings.

Concrete and steel are the two materials mainly used in foundations and substructures. Both materials require large amounts of energy in their manufacture. The cement contained in concrete also involves release of CO_2 in the fabrication process. Moreover, the construction of traditional foundations and substructures consumes a considerable volume of materials, which means a high impact at the transportation stage.

Foundations and substructures represent, therefore, a strategic research area for reducing the embodied energy and carbon of construction.

1.2 Materials and waste reduction

Given the quantities of materials traditionally used in foundations and substructures, there is great scope for reducing the scale of resource use. Solutions include re-using materials, recycling aggregates, incorporating cement replacement additives, and using more sustainable forms of construction material. Approaches such as responsible sourcing of materials have a role in driving this change. Different standards have recently been developed to this end, including BES 6001.

The construction sector is responsible for one third of the waste produced in the UK. The excavations necessary for foundations and substructures contribute a large part of this waste. The Department for Environment, Food and Rural Affairs (DEFRA) provides guidelines concerning waste, introducing the waste hierarchy, which ranks the actions to undertake: waste prevention, preparing for re-use, recycling, other recovery and disposal.

Waste hierarchy	
Prevention	'Using less material in design and manufacture. Keeping products for longer; re-use. Using less hazardous materials.'
Preparing for re-use	'Checking, cleaning, repairing, refurbishing, whole items or spare parts.'
Recycling	'Turning waste into a new substance or product. Includes composting if it meets quality protocols.'
Other recovery	'Including anaerobic digestion, incineration with energy recovery, gasification and pyrolysis which produce energy (fuel, heat and power) and materials from waste; some backfilling.'
Disposal	'Landfill and incineration without energy recovery.'

Source: Defra (2011) *The Guidance on applying the Waste Hierarchy,* accessed 19th March 2015 https://www.gov.uk/government/publications/guidance-on-applying-the-waste-hierarchy

New designs for foundations and substructures should seek to reduce their volume, which will reduce both the amount of material used and the amount of waste produced by excavations.

1.3 Maintained natural water cycle and enhanced aquatic environment

Construction can have a significant effect on the aquatic environment; water depletion and pollution are environmental, economic and political issues. The authors of 'Sustainable Geotechnics' highlight a number of issues to consider concerning the protection of water resources:

- Safeguarding and enhancing the quantity and quality of water in lakes, rivers and groundwater
- Minimising the project's impact on local water systems and their functions
- Minimising the project's impact on the wider water cycle and its dependants
- Valuing water appropriately in optimising project development, construction and operation choices
- Safeguarding tidal systems including their salinity gradients
- Maintaining seawater quality
- Minimising impact on coastal processes, including sediment erosion and deposition

1.4 Effective land use management

The last 50 years have seen unprecedented demands on space. Major world cities such as London are experiencing population growth; combined with a trend towards smaller households, this places greater pressure on housing and land prices. The demand for greater mobility and the distribution of consumer goods has led to new requirements for transport infrastructure. The growing expansion into green-belt areas is fiercely resisted and construction in flood-plain areas such as the Thames estuary brings risks connected with the increased risk of flooding due to climate change. However, there are 300,000 hectares of brown-field land in the UK and government policy continues to encourage its use for new development. Further details can be found in BRE report 447 *Brownfield development sites: ground-related risks for buildings* (2002). The report is concerned with those aspects of risk management for building developments on brownfield sites that involve ground-related hazards for the built environment, but it emphasises that an unwarranted over-sensitivity to risk will defeat the objective of locating building developments on brownfield sites. This report outlines a systematic means of managing the range of risks to the built environment over the lifetime of the building development. Principal hazards are ground movement, vulnerability of construction materials to aggressive ground conditions, gas migration, and subterranean fires.

There is also scope for built development to spread upwards and downwards, as well as sideways. Optimising vertical space, both underground and overground, will have an effect on substructures as loads increase and engineering challenges become more complex.

1.5 Relative impact of foundations and substructures

The nature of a building's substructure can make a big difference to its contribution to global warming. A 2009 study of embodied CO_2 and emitted CO_2 from new buildings for the Scottish Government found that the foundations and substructures of four sample buildings was the second or third biggest contributor to the buildings' embodied CO_2, ranging from 14% to 27% of the total (Scottish Government, 2009 and Menzies, 2011).

Concrete has typically been much the most important load-bearing material used in foundations and substructures over the last century. It is also the principal reason why foundations and substructures embody so much carbon: concrete foundations and substructures are typically massive, requiring the extraction and transport of large volumes of raw materials.

Nonetheless, some substructure solutions can be designed to capture ground or geothermal energy, so reducing the building's carbon emissions in use. This is typically achieved through ground source heat pumps incorporated vertically into piles or horizontally into foundations.

Part 2 Mitigating the environmental impact of foundations

Reducing the impact of foundations

Four main ways of reducing the environmental impact of new foundations and substructures have been identified in research on Sustainable Substructures for the BRE Trust. Each is summarised below. Furthermore, the reuse of existing foundations and substructures could also be developed as a response to the scarcity of land available for re-development in inner cities. Further information can be found in Reuse of foundations for urban sites: Proceedings of the International Conference (2006)

2.1 Reducing the loads applied to the foundations and substructures by the building

Perhaps the most obvious first step in reducing the environmental impact of building foundations and substructures is to reduce the weight of the structure to be supported, thus reducing the size of the required foundations and substructures and potentially allowing a greater range of foundation options for any given ground conditions.

The gradual move away from traditional full masonry construction in housebuilding, first to masonry using increasingly lightweight blocks, then to timber framed with masonry cladding, has significantly reduced foundation loads.

The benefits of these weight reductions in the external walls are already available for utilisation in the foundation design process. There is considerably greater potential for load reduction through the use of off-site system construction technology, such as architectural façade panels (see Figure 1) or structural insulated panel systems (SIPS) similar to those used in the Kingspan Lighthouse, a Zero-Carbon Home showcased on the BRE Innovation Park at Garston 2007 to 2012 (Figure 2).

Figure 1 Architectural façade panel system; Kingspan

Figure 2 Structurally Insulated Panels (SIPs) were used in the Kingspan 'Lighthouse'

2.2 Improving traditional methods

Innovations in foundations and substructures design and application should significantly reduce embodied carbon in foundations. However, potential savings in the use of traditional concrete foundations and substructures are also available through better design and site processes.

Reducing concrete in foundations

The largest contributor to carbon weighting in the majority of foundation works is concrete. This has traditionally been, in one format or another, the principal means by which structural loads are transferred to the ground.

The overall depth of the foundation trench is influenced by ground and climatic conditions. For speed and convenience, a general method, using large quantities of concrete, became increasingly common practice from the 1970s onward. The deep trench method uses three or four times more concrete than strip footings. In addition to the embodied impact of concrete, digging oversized foundations and substructures produces excessive excavation waste, so the benefits of reducing the volume of concrete employed are twofold.

Better design related to specific site conditions would be beneficial. Tighter specification and control of the works should also minimise the impact of continued use of this approach. However, unless there is an incentive for change, be it legislative, by enticement through credits within schemes like BREEAM, or ultimately through prohibitive concrete costs, it will be difficult to make large improvements in the sustainability of this approach.

Improving concrete design

The single technical requirement of a trench fill foundation is to transmit structural loads to the desired depth in the ground; this requires a relatively low concrete strength. Low-embodied-energy alternative materials such as secondary or recycled aggregates and cement replacements such as pulverised fuel ash (PFA) or ground granulated blast furnace slag (GGBS) could therefore be employed without compromising the performance of the foundation. Where tensile strength of the concrete is particularly relevant, for example in thin raft design, the appropriate use of reinforcement (almost all produced from recycled steel) can compensate for weaker concrete.

2.3 Alternative low-carbon technologies

Some of the innovations are increasingly available on the market at reducing embodied energy, often in materials, manufacture and installation. The so-called 'system foundations' potentially offer substantial reductions in embodied energy compared with traditional high volume concrete solutions, such as deep strip and raft foundations. In poor ground conditions or where high building loads are to be applied, even traditional piling techniques may offer the most energy efficient solutions.

The advantages gained above ground with modular and system ground floor construction can be further enhanced as these foundation and flooring systems are compatible with all piling systems, including driven precast concrete or steel piles, CFA (Continuous Flight auger), SFA (Segmental Flight Auger) or CHD (Continual Helical Displacement) and steel helical (screw) piles.

2.4 Improving the load-bearing capacity of poor ground

Where ground conditions are inadequate to provide the necessary support to a structure using simple 'low energy' foundations and substructures solutions, alternative methods are often then automatically considered, which can involve a substantially higher level of embodied energy. 'Ground improvement' could be a solution to enable the ground to support greater loads and then allow the use of a simple low-carbon foundation. This combined approach may have a lower total environmental impact than a single more complex solution.

The 'Ground improvement' column in the flow charts (figure 3) contains a wide range of commonly adopted techniques for improving the engineering properties of poor ground. They comprise three basic approaches:

- **Physical additions** to the existing ground mean basically the use of vibration treatment to improve the load-bearing capacity of soils.
- **Mechanical improvement** may use loadings or methods involving removal and re-compaction of the ground.
- **Chemical modification** can be achieved by mixing with the soil or injecting into the ground an additive which will reduce its permeability or improve its load-carrying properties.

Although chemical modification techniques described above are predominantly used as ground improvement prior to development, grouting treatment by injection can also be used to remediate existing foundations.

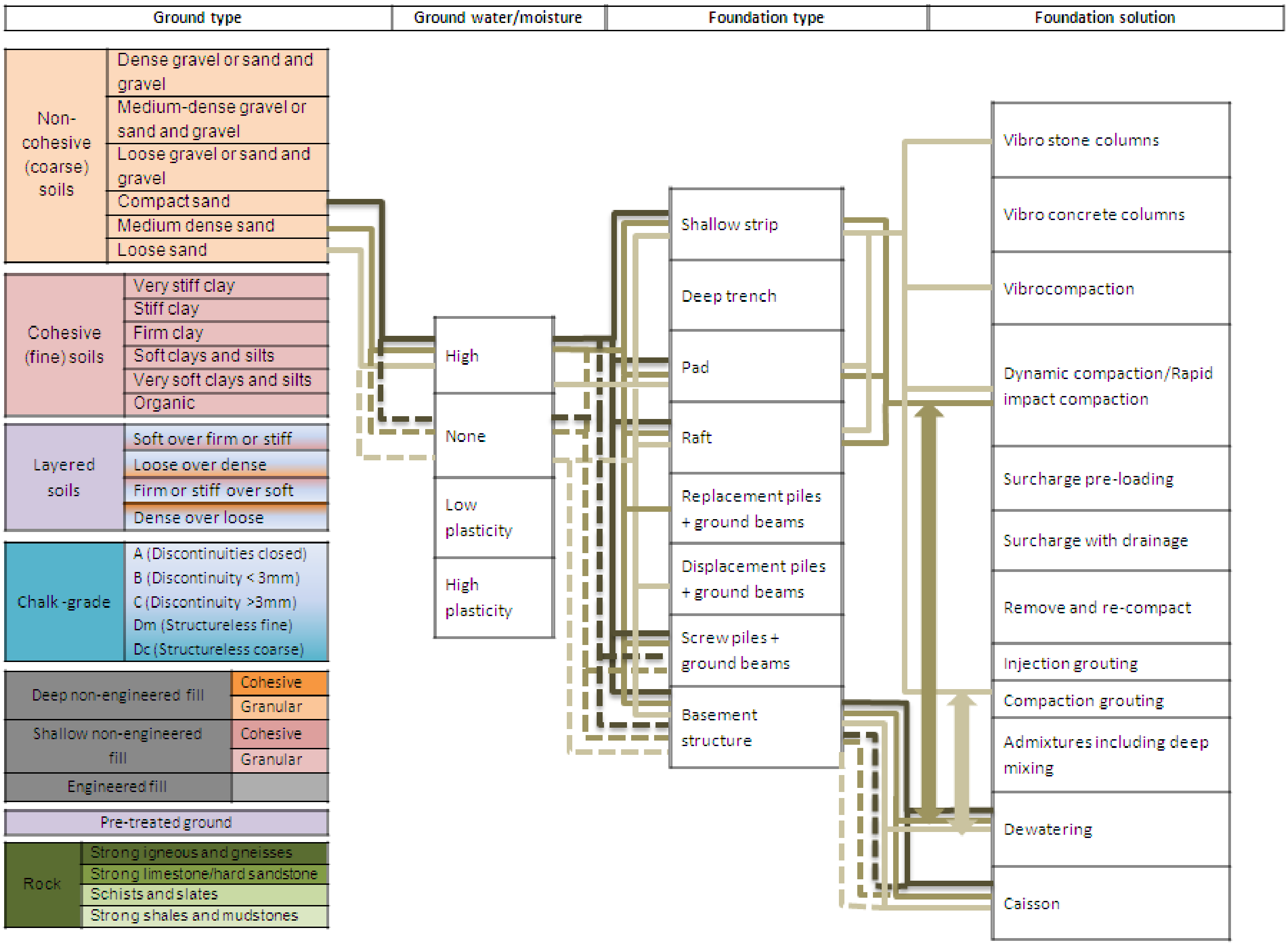


Figure 3 Example of flow chart

2.5 Reuse of existing foundations

Ground congestion is and has been one of the prime drivers for the reuse of foundations and substructures in urban areas and will become more critical as urban centres become more crowded. The most common type of foundation considered for reuse is piles. The reuse of existing foundations and substructures offers economic and environmental advantages, and allows the preservation of any archaeology.

2.6 Compensating for the impact of foundations

The building of new substructures could be an opportunity (ICE, 2012) for the development of alternative means of energy generation in using geotechnical resources. The ground is not only a support for the structure; it can also be used for providing energy. Geothermal energy is heat stored in the earth's core, originating from the radioactive decay of minerals and solar energy absorbed at the surface. Uses of geothermal energy include electricity generation, district heating and ground source heat pumps.

Using substructures as part of energy storage and production systems could provide a means of compensating for the unavoidable environmental impact of the foundations.

Part 3 Future approaches to the assessment and selection of foundation and substructure solutions

Earlier discussion has highlighted that foundations and substructures have the potential to make a significant contribution to the embodied environmental impacts of a building. While the embodied impacts can be understood and mitigated in individual cases assessing them using an elemental based rating system has remained a challenge that has not been overcome. As a consequence environmental rating schemes like BREEAM tended not to include foundations and substructures.

The following sections point to a future where the integration of foundations and substructures into whole building assessments can happen.

3.1 Decision making process – selection of solutions

To help inform the decision making process BRE has developed a flow chart to identify suitable foundation and substructure solutions, depending on the geotechnical constraints imposed by ground type and the moisture characteristics of the ground (Figure 3). Ground type and soil moisture content are important considerations and the flow chart presents the user with likely foundation types and possible ground improvements based on the prevailing site conditions. The flowcharts work on the premise of addressing each of the relevant factors in turn and discounting solutions that are not suitable for the site conditions.

For example, if a building's foundations and substructures are to sit on very soft clays or silts, the decision tree uses data about the ground water (classed as either high or none). If the groundwater is none, the tool suggests that only three out of a possible eight foundation types are suitable. If the user then picks one of these types, for example a basement structure, they are presented with two types of ground improvement suitable for basement structures on dry very soft clays or silts.

Having validated this process the future integration into a 'BIM' (Building Information Modelling) tool is the logical next step. This will allow the embodied impacts of proposed solutions to be calculated and options (if available) to be compared.

This step has already been achieved for both the superstructure and foundations and substructures with the IMPACT methodology.

3.2 IMPACT – Whole Building Assessment Tool

IMPACT is a BIM solution for Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). It is a specification and database for software developers to incorporate into their tools to enable consistent LCC and LCA modelling. The first IMPACT compliant BIM tools were released in 2013. While the first IMPACT compliant tools utilise LCA data from Environmental Product Declarations (EPD) to BRE's 2008 methodology by the autumn of 2015 they will be using EN15804 EPD that follow BRE's Product Category Rules (PCR) and BRE recognised data sources.

IMPACT works within BIM applications where the user attributes environmental and cost information to drawn or scheduled entities. This may be done as a 'check' at particular stages in design development or, better still, iteratively as part of the user's general workflow. IMPACT measures the quantity of information in the BIM and multiplies this with environmental impact and cost 'rates' to produce an overall impact and cost for the whole or a selected part of the design. Fundamentally, the results generated allow the user to develop low impact building designs from scratch or identify aspects of a partially complete design where cost and environmental 'savings' can be made. In addition, the overall results for the design can be compared to a suitable benchmark to assess general performance. Foundation and substructure solutions can be included in the assessment.

In summary the results generated by IMPACT allow the user to:

– analyse the design to optimise cost and environmental impacts of the whole building;
– make early and informed decision for the choice of materials and design;
– include foundations and substructures;
– contribute towards credits in building level assessment schemes, such as BREEAM.

IMPACT is currently (2015) available via the IES tool (IES VE: www.iesve.com), which is a tool that allows the modelling of the thermal performances of a whole building. Combined with the IMPACT module, the IES software is able to provide a powerful tool that allows the users to calculate the thermal performances of the buildings while making informed decision on the embodied carbon impact and the whole life costing. Licenses for IMPACT are available via IES through the IES VE software.

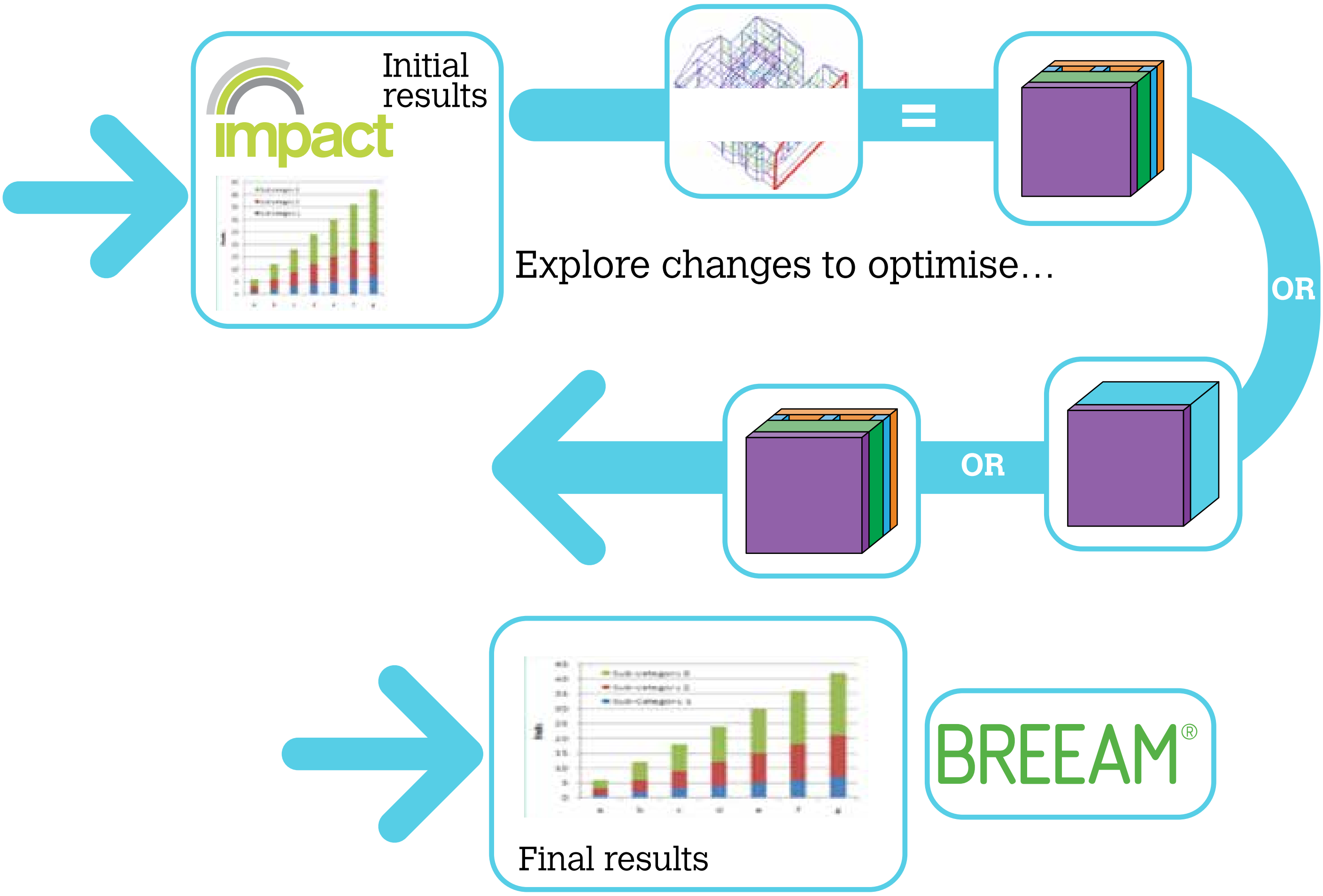


Figure 4 Impact allows designers to make informed descisions

3.3 The way forward

IMPACT now provides a solution within BREEAM that will assess the embodied impacts of foundations. IMPACT will also provide the means by which, at an individual building level, the embodied impacts of different foundation and substructure solutions can be compared. The complexities associated with ground conditions at different sites mean that the creation of industry-wide benchmarks – in the style of the Green Guide – for foundation and substructure solutions will remain a challenge for the short term at least.

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