



Thermal Pile Design, Installation & Materials Standards

Issue 1.0

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GSHP

association

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1.0 PREAMBLE

1.1 Introduction

The Ground Source Heat Pump Association (GSHPA) has recognised that the industry, including consumers and industry members, require installation standards in order to maintain a high level of installation quality whilst protecting the environment to ensure “Best Practice”.

The standards are aimed at the designers and installers of ground source systems, architects and engineers specifying ground source systems and main and sub-contractors involved with installer companies supplying ground source systems or designs.

The standards should also prove to be a useful document for the general public and anybody else with an interest in the subject, when considering a ground source installation.

This thermal pile standard has been developed from the GSHPA borehole loop guide¹.

Additional information is provided in the appendices on certain topics associated with ground source systems that are either the subject of current research or where further research is required, and it is not possible to give prescriptive guidance on these topics at this time.

1.2 Definitions

Heat pump	A device which uses heat energy from a low temperature source and uses it for space or hot water heating by converting the heat energy into a higher temperature.
Ground source heat pump (GSHP) system	A heating or cooling system that works by using the ground as a heat source or heat sink, including the heat pump.
Ground (source) heat exchanger (GHE)	A ground heat exchanger comprises an open loop system or arrays of horizontally or vertically installed closed loop systems. The ground heat exchanger can be installed using an array of boreholes, piles, pond loops, or horizontal collectors that are exchanging heat with the ground around them. This includes header pipes to the plant room, internal pipework up to and including manifolds and/or flushing valves/arrangement and excludes the heat pump and circulation pump.
Closed loop	A sealed loop of pipe placed in the ground and filled with thermal transfer fluid. Only closed loop thermal piles are considered in this document.
Open loop	System in which water is abstracted from the ground and passed through a heat exchanger before normally being discharged to the ground again (this type of system is outside the scope of this document).
Thermal / Energy foundations	Any type of foundation (walls, piles, slab) that exchanges heat energy with the ground.
Thermal piles	Load bearing piles with closed loop pipes embedded or attached to the piles. The term “thermal pile” comprises both the pile and the loops. The term “energy piles” has not been used to avoid the conflict with trademarks.
Thermal walls	Retaining walls with closed loop pipes embedded in the concrete. These walls may be load bearing.

¹ GSHPA (2011) Closed-loop Vertical Borehole: Design, Installation & Materials Standards, Issue 1.0.

Thermal loops	A closed loop of pipework within the pile carrying thermal transfer fluid.
Header pipes	Network of pipes connecting the piles to the plant room.
Thermal transfer fluid	Fluid that circulates through a closed loop system generally containing antifreeze, biocide and corrosion and scale inhibitor.
Thermal response test	A test normally carried out during site investigation works to determine the thermal properties of the ground.
Seasonal Performance Factor (SPF)	This is the ratio of the heat delivered by the heat pump, to the energy supplied to power the heat pump, over a set time period (typically one year).

Detailed definitions of roles and responsibilities of the design and construction team members are given in Section 3.0, however brief definitions of the parties involved are given below.

Employer	The Employer or Client is the project funder in contract with the Engineer and Main Contractor.
Engineer	A term used in SPERW (ICE ²) for a qualified or suitably experienced engineer who is appointed by the Employer to act as their representative on the pile design, specification and supervision of the project.
Structural Designer	Person or organisation responsible for the design of structural elements to resist structural loads.
Pile Designer	Person or organisation responsible for the design of structural piles to current codes and standards, which meet the building load requirements.
GSHP Designer	Person or organisation responsible for the design and performance of a GSHP system which meets the energy requirements specified in the contract specification and drawings.
M&E Designer	Person or organisation responsible for the integration of the ground source heat pump design solution into the mechanical and electrical system. The M&E Designer is also responsible for defining the building thermal loads and the performance requirements for the GSHP system.
Main Contractor	The Main Contractor (or Principal Contractor in CDM regulations) is appointed by the Employer and has overall responsibility for the works.
Piling Contractor	Person or organisation responsible for construction of piles and maintaining integrity of pile loops during piling construction works.
GSHP Contractor	Person or organisation responsible for provision and installation of the GSHP system.
Groundworks Contractor	The groundworks contractor is responsible for trimming the piles and for safeguarding the integrity of the loops during this operation.
M&E Contractor	The M&E Contractor is responsible for the connection of the mechanical and electrical plant to the GSHP system and may also be responsible for delivering the specified heating and cooling profile to the building.

² Institution of Civil Engineers (2007) The Specification for piling and embedded retaining walls, 2nd edition.

1.3 Scoping Statement

The GSHPA standards are designed to be a concise document providing information for the materials and general specification of a closed-loop thermal pile system. The standards also cover internal pipework up to and including manifolds and/or flushing valves/arrangements up to the entrance of header pipes into the plant room. They are not designed to be an installation or training manual and the standards must be referred to in conjunction with recognised design qualifications and training programmes. Therefore, no responsibility can be accepted by the GSHPA for the performance of GSHP systems.

The standards are designed so as to enable anybody reading them to quickly reference minimum materials specification, techniques and qualification requirements to be met and ensure that they either comply with the standards (or exceed them) or are employing companies and personnel who comply with the standards (or exceed them). Where references are not yet available to support the standard, additional information is provided in appendices.

1.4 Acknowledgements

The standards have been developed by the GSHPA Training & Standards Sub-Committee (T&SC) working party. Thanks from the association and members must go to the working party members for their efforts which have been provided at their own expense and time. Support has also been provided by the GSHPA secretariat.

The thermal pile working party comprised:

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Kenichi Soga	University of Cambridge
Nic Wincott	NeoEnergy (Sweden) Ltd.
Christopher Wood	University of Nottingham / Roger Bullivant Ltd.

2.0 REGULATORY & GOVERNMENT AGENCY REQUIREMENTS

2.1 Health & Safety at Work Act '74, Management of Health & Safety at Work Act '99

The Health and Safety at Work Act 1974 and The Management of Health and Safety at Work Act 1999 shall be adhered to at all times. Both acts apply to every work activity.

2.2 The Construction (Design & Management) Regulations 2007 (CDM 2007)

The CDM Regulations 2007 apply to all construction work in Great Britain and, by virtue of the Health and Safety at Work Act 1974 (Application outside Great Britain) Order 2001, its territorial sea, and apply to both employers and the self-employed without distinction. Reference shall be made to the Health & Safety Executive (HSE) Approved Code of Practice¹ with respect to implementation of and adherence to the CDM Regulations 2007.

2.3 Groundwater Protection – Policy & Practice

No specific requirements regarding the control of heat in the environment are currently detailed in legislation or statutory guidance. Groundwater Protection; Policy and Practice² (GP3) provides guidance on the Environment Agency's position with regard to the regulatory constraints which they may impose on Ground Source Heat Pump Systems (GSHPs) and provides guidance on the preferred planning and risk assessment procedures which shall be referenced and should be employed. The Environment Agency 'Good Practice Guide', 2011³ explains how the environmental risks of a ground source heating and cooling scheme can be reduced. For clarification, these documents, along with the Environment Agency itself if necessary, shall be consulted early on in the planning process. In Northern Ireland and Scotland the equivalent agencies NIEA (Northern Ireland Environment Agency) or SEPA (Scottish Environment Protection Agency), shall be consulted if necessary.

2.4 The Coal Authority

The Coal Authority shall be contacted to ascertain whether the proposed piling site is within an area under the jurisdiction of the Coal Authority by postcode at www.coal.decc.gov.uk.

Where proposed works will intersect, enter or disturb the Coal Authority's property it is a prerequisite that its prior consent be obtained. In the case of an accident occurring, if it is established that a contractor has knowingly undertaken work which was advised against by a competent authority, or that they have knowingly circumvented authorised schemes designed to ensure safety, this may be seen as an aggravating factor in any potential prosecution of the company. A joint Coal Authority/British Drilling Association/Health & Safety Executive guidance document is available, detailing particular risks⁴.

2.5 Building Regulations & Other Certification Material

Relevant local, regional and national building & water regulations still apply and many of these documents are referenced in Microgeneration Installation Standard: MIS3005, the heat pump installation standard⁵.

¹ HSE (2007) Managing Health and Safety in Construction. Construction (Design and Management) Regulations 2007 Approved Code of Practice. HSE Books.

² Environment Agency (2007) Groundwater Protection: Policy and Practice.

³ Environment Agency (2011) Environmental good practice guide for ground source heating and cooling schemes.

⁴ Coal Authority (2012) Guidance on managing the risk of hazardous gases when drilling or piling near coal, v1.0.

⁵ DECC (2012) Microgeneration Installation Standard 3005: Requirements for contractors undertaking the design, supply, installation, set to work commissioning and handover of microgeneration heat pump systems, Issue 3.1a.

2.6 Planning Permission Requirements

Most ground source heat pump installations are classed as permitted development. Please check General Permitted Development Order in the Town & Country Planning Act 2008 (No.2362 1st October 2008) for full details.

2.7 Notification to the British Geological Survey

No notification is required for closed-loop systems, but it is regarded as good practice to notify the British Geological Survey of the drilling of any borehole deeper than 15m and to provide them with information on the borehole's location and a copy of the geological drilling log. A form of notification may be found at www.bgs.ac.uk. Notification is obligatory for any borehole designed to investigate or abstract groundwater.

2.8 Party Wall Issues

All systems shall be designed assuming that adjacent systems will be installed and will therefore have a right to the heat under their property.

2.9 ICE Specification for Piling and Embedded Retaining Walls (SPERW) 2007⁶

The ICE SPERW outlines the requirements and responsibilities for parties involved with the design and construction of piles and retaining walls. There are three sections to the document:

- Part A - General guidance
- Part B - Specification requirements
- Part C – Guidance notes

The SPERW Part A covers general project specific details on the installation of piles that can be extended to cover the installation of thermal piles in conjunction with this document.

The Part B sections that are of particular importance to thermal piles include bored piles (B3), CFA piles (B4), diaphragm walls and barrettes (B8), secant pile walls (B9), contiguous pile walls (B10) pile testing (B15) and pile instrumentation (B17).

The SPERW Part C provides guidance notes including details of the roles involved in the design and construction of piles and walls. The GSHPA Thermal Pile standard (this document) sets out the additional allowances that shall be considered to incorporate thermal loops within the piles.

2.10 Design Codes

There is an extensive framework of codes for pile and retaining wall design. These include:

- BS EN 1997-1:2004 Eurocode 7: Geotechnical design - Part 1: General rules, BSI
- BS EN 1997-2:2007 Eurocode 7: Geotechnical design - Part 2: Ground investigation and testing, BSI
- BS EN 1536:2010 Execution of special geotechnical works — Bored piles, BSI
- BS EN 1538:2010 Execution of special geotechnical works — Diaphragm walls, BSI
- BS EN ISO 22477-1 (draft) Geotechnical Investigation and Testing, Part 1 - Pile load testing by static axially loaded compression, BSI
- BS5930: 1999 + A2:2010 Code of practice for site investigations, BSI

⁶ Institution of Civil Engineers (2007) The Specification for Piling and Embedded Retaining Walls, 2nd edition.

- BS EN 15450:2007 Heating systems in buildings - Design of heat pump heating systems, BSI
- BS EN 12664:2001 / BS EN 12667:2001 Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods, BSI
- BS EN 206:2000 / BS 8500:2006 Concrete - Specification, performance, production and conformity, BSI

2.11 Installation Standards

The current version of the following document should be referred to for guidance on the installation of heat pump systems. MIS3005 applies to systems up to 45kW thermal (kW_{th}); however the guidance may also have application for larger systems.

- Microgeneration Installation Standard: MIS 3005 Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of Microgeneration heat pump systems, Microgeneration Certification Scheme.

2.12 Other Codes of Practice, Guidance and References

A list of recommended reading guidance and policy documents from other agencies are included at the end of this document. References supporting the design of thermal piles are also given in footnotes throughout this document; however for an up-to-date reference list refer to the GSHPA website (www.gshp.org.uk).

3.0 CONTRACTUAL RESPONSIBILITIES

3.1 Preface

The design and construction of the thermal piles and connection of the thermal loops and pipework through the foundations to the plant room requires interfaces between many different disciplines with different responsibilities and competencies. Special consideration needs to be given to contractual arrangements because the piles must function as an efficient thermal system, as well as a providing safe support for the structural loads.

The design phase of the thermal pile system requires a thorough site survey and characterisation, geothermal information, accurate structural and thermal load modelling, and reasonable assurance that the design chosen meets the design intent.

3.2 ICE SPERW

For non-thermal piles, the ICE SPERW¹ sets out clearly the responsibilities for Engineer design and for Contractor design in Section C1.4 and Table C1.1. For thermal piles, the split of responsibility needs to be further defined, extending Table C1.1 with an additional row as shown below:

Design Responsibility	Engineer	Contractor
1. Design of foundation scheme (including SWL and pile location)		
2. Choice of piling or walling method		
3. Design of piles of wall elements to carry Specified Loadings		
4. <i>Design of thermal loops to provide specified thermal loading</i>		

Table 3.1: Modifications to ICE SPERW Table C1.1 to include the thermal loop design

There are additional roles and responsibilities necessary for the design and construction of thermal piles as set out in Figure 3.1 to Figure 3.4 below. Each party and their responsibilities in the process of design through construction to performance monitoring are considered individually below. Generally the GSHP Designer may be linked to the Pile Designer for Engineer design of piles (Figure 3.1 and Figure 3.3), or to the Piling Contractor in the case of Contractor design of piles (Figure 3.2 and Figure 3.4).

¹ Institution of Civil Engineers (2007) The Specification for Piling and Embedded Retaining Walls, 2nd edition.

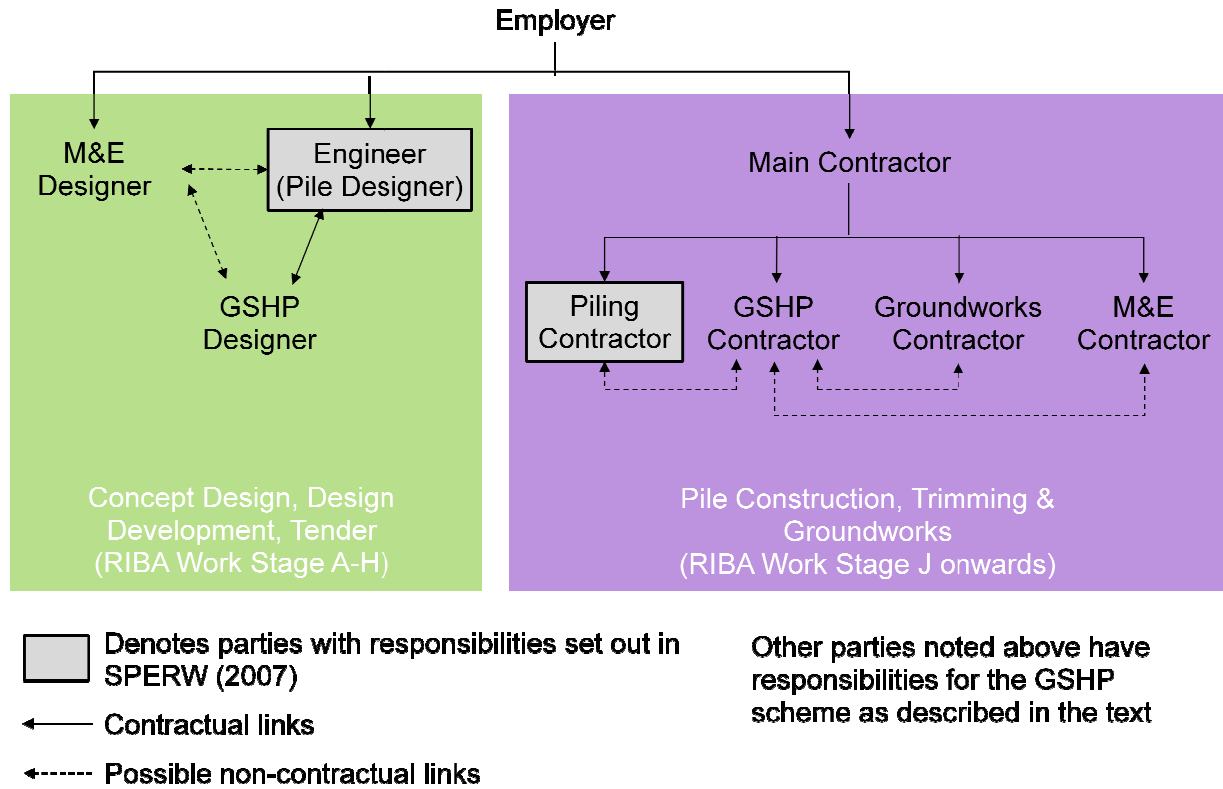


Figure 3.1: Engineer Design based on ICE SPERW C1.4

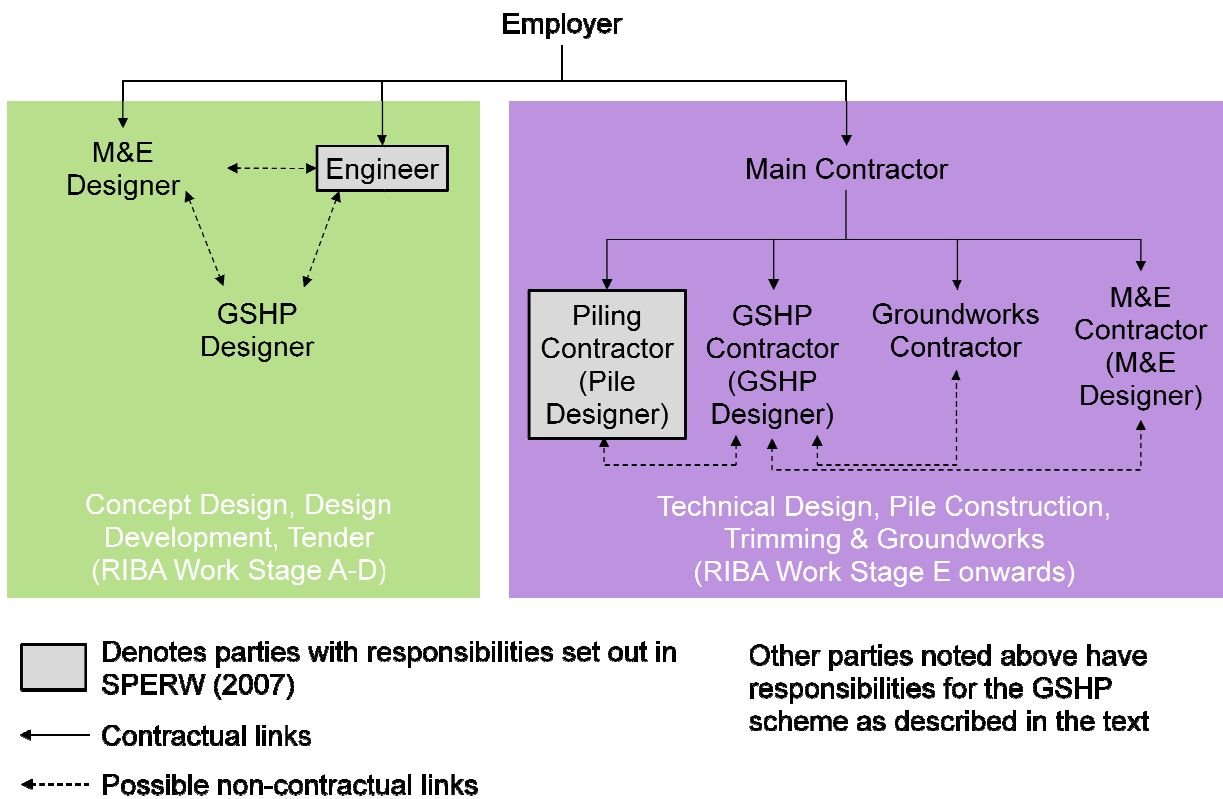


Figure 3.2: Contractor Design based on ICE SPERW C1.4

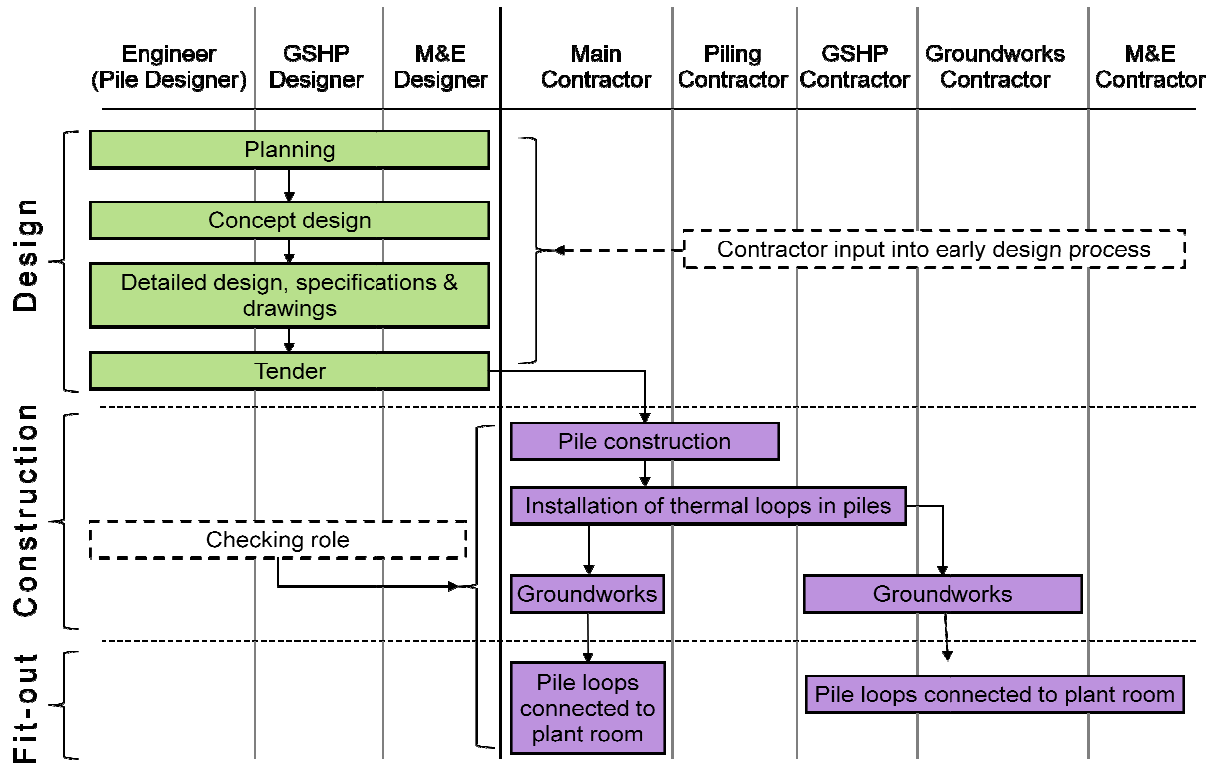


Figure 3.3: Expected responsibilities – Engineer Design

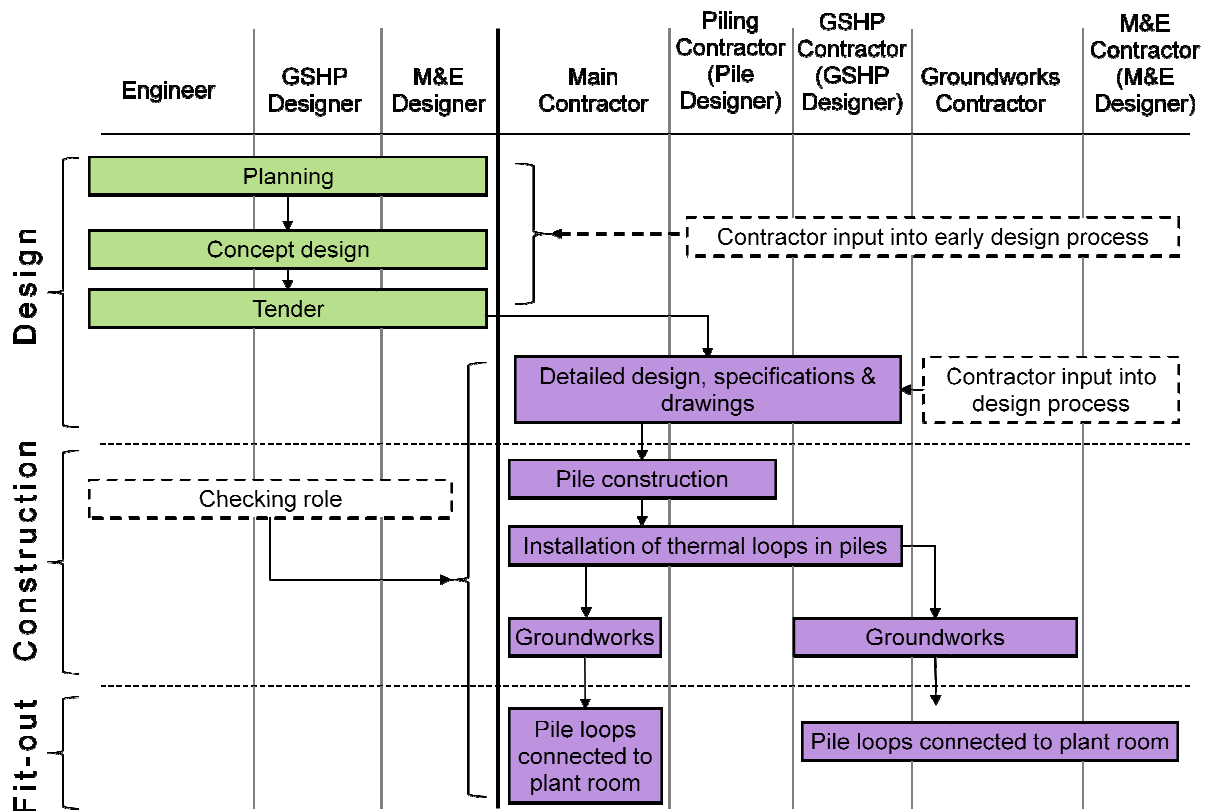


Figure 3.4: Expected responsibilities – Contractor Design

In many cases the GSHP Designer may also be from the same organisation as the GSHP Contractor (Figure 3.1 to Figure 3.4). Contractual responsibilities may also differ depending on the contract requirements.

During planning, design and construction stages, the management of the interface between all the interested parties will need to be managed carefully. It is recommended that at the construction and fit out stages a “Co-ordinator” is identified to oversee the interfaces. The Co-ordinator should be from the Main Contractor’s organisation.

3.3 Employer or Client

Under SPERW the Employer has contractual relations with the Engineer and the Contractor (Main Contractor), see Figure 3.1 and Figure 3.2. The Employer is the project funder with health and safety obligations and other responsibilities.

3.4 Engineer

The role of the Engineer is described in ICE SPERW as ‘a qualified or suitably experienced engineer who is appointed by the Employer to act as their representative on the design, specification and supervision of the Works’. Under the Engineer Design approach (see Figures 3.1 and 3.3) the Engineer is the Pile Designer and their organisation will also have responsibility for the thermal effects on the pile design. He needs strong links to the M&E Designer. Contractors may give non contractual input at the planning and design stage, see Figures 3.3 and 3.4.

3.5 Pile Designer

The Pile Designer is responsible for the design of structural piles which meet the requirements of the loads of the building and which meet the requirements of current European design standards such as BS EN 1997-1:2004. The Pile Designer is responsible for the choice of piling technique, performance of the piles and their ability to carry the specified loading regime in accordance with the relevant specification(s). In addition he should consider the effect of both the pile and ground temperature range as proposed by the GSHP Designer, on the pile capacity, concrete stresses and pile settlement performance.

3.6 GSHP Designer

The GSHP Designer is responsible for the design and performance of a ground energy system which meets the energy requirements specified in the contract specification and drawings. This may follow discussions with the M&E Designer and Contractor input. The design of the system may include modelling to determine the length of heat exchanger required to meet the energy demands. The GSHP Designer will define the temperature changes in the pile and ground which will be used by the Pile Designer.

The GSHP Designer will produce a thermal loop design that meets the design intent and which ensures the inflow temperature of the ground energy system at all times remains within specified limits to be agreed with the Pile Designer. Where possible, the GSHP Designer should maximise the Seasonal Performance Factor (SPF) of the GSHP system.

The GSHP Designer is also responsible for the design of the header pipes and circulation pump(s) to interface with the heat pump including the header pipe layout drawings and details. The GSHP Designer should also be responsible for the heat pump selection and design, however if the GSHP Designer is not responsible for the heat pump package, full details of the selected heat pumps must be made available to the GSHP Designer so that proper evaluation of the actual ground thermal loads (heat of extraction and heat of rejection) can be made.

Where appropriate, the GSHP Designer shall produce the operation and maintenance (O&M) manual section on the heat pump and the GSHP system. This shall include the monitoring trigger criteria (see Section 3.14).

3.7 Mechanical & Electrical (M&E) Designer

The M&E Designer is responsible for the integration of the ground source heat pump design solution into the mechanical and electrical system by providing a building heating and cooling demand profile which will be used to design the ground energy aspect of the thermal pile. The need for accurate and robust building demands is of high importance to the GSHP Designer to allow the system to be designed efficiently. A significant under - or overestimate of the building loads can lead to the thermal pile system being compromised, leading to unacceptable pile cooling or heating, or at worst, can cause systems to not work.

The performance requirements for the system (load side temperatures, heat pump coefficient of performance (COP), SPF, peak load, annual loads) need to be specified by the M&E Designer to meet their general compliance issues. The M&E Designer must also link the GSHP system into the overall heating and cooling design.

3.8 Main Contractor

The Main Contractor (or Principal Contractor in CDM regulations) shall have overall responsibility for the works, which may be carried out by specialised subcontractors. The Main Contractor is best placed to take the Co-ordinator role to manage interfaces between the construction team members.

3.9 Piling Contractor

The Piling Contractor shall be responsible for the installation of piles to meet the contract specification (including those of SPERW if applicable) and any requirements noted on contract drawings. In addition, he shall also work to the thermal installation specification/method statement and maintain the integrity of the specified thermal loops during the pile installation process (refer to Section 10 for thermal loop testing details during the installation process). This work may include but is not limited to; construction of piles at correct locations, preparation of record drawings, integrity testing of foundation piles, production of pile construction records.

Although the Piling Contractor may not be in contract with the GSHP Designer / Contractor, it is good practice for the parties to be in dialogue to ensure mutual understanding and successful delivery of the thermal requirements.

The Piling Contractor may also be the Pile Designer where Contractor design of piles is specified, see Figure 3.2 and Figure 3.4.

3.10 GSHP Contractor

The GSHP Contractor shall be responsible for the installation of heat exchanger loops into the piles as specified by the thermal loop design. This work includes but is not limited to ensuring that work is carried out to the specification and drawings in terms of the length of pipe used, the position of the loops within the pile, the method of attaching the thermal loops to the pile cage, ensuring the integrity of the loops within the pile during construction and where necessary, an assessment of damage to the loops.

Where the thermal loop installation is undertaken by the Piling Contractor, the GSHP Contractor shall be responsible for conducting regular checks on the Piling Contractor to monitor and test the thermal loop installation on the pile cages and the cage installation in the piles.

The GSHP Contractor also has a role to test the thermal loops before and after the groundworks and is responsible for the installation and testing of all header pipes at the surface and normally the connection of these pipes to the plant room.

3.11 Groundworks Contractor

The Groundworks Contractor is usually responsible for trimming the piles and is responsible for safeguarding the integrity of the loops during this operation. He should also ensure that no damage occurs to the header pipes and associated equipment.

3.12 M&E Contractor

The M&E Contractor is responsible for the connection of the load side pipework to the heat pump and the installation of the specified plant room equipment necessary for the operation of the thermal piles.

3.13 Loop & Pipework Testing Responsibilities

It is good practice that between any handover of loops appropriate testing is carried out. Handover stages generally occur at:

- Loop fabrication
- Pile installation
- Before and after headering
- Any contractual handover of loops between parties

The responsibility for testing different parts of the overall system including the integrity of the thermal loop installation and testing at handover will be undertaken by different parties as outlined in Section 0.

3.14 Monitoring and Checking Performance against Design Criteria

The performance of the ground energy system will be monitored to ensure that the inflow temperatures to the pile do not fall outside the design limits, see Section 5.7.3, Section 14.0 and Appendix A. This will be achieved by monitoring of the Building Management System (BMS) and in particular the inflow and outflow temperatures to the heat pump. Trigger values should be set so that if temperatures operate outside this range the system should be automatically disabled and notification shall be sent to responsible persons (e.g. Building Manager) who can rectify the situation. Should the thermal pile system be operating outside of the appropriate temperature range, the original design team should be required to investigate if the system is functioning as designed.

Information should be included within the building's operations manual to ensure appropriate monitoring is carried out. This should be specified by the GSHP Designers early on in the process.

4.0 DESIGN & INSTALLATION: PERSONNEL & TRAINING REQUIREMENTS

4.1 Introduction

This section indicates the minimum training standards that are required by the various contractual parties to fulfil their contractual obligations and to ensure 'Best Practice' in the installation of a ground source heat pump system. Other guidance should be sought on general designer and contractor training competencies, e.g. CDM regulations.

Directive 2009/28/EC of the European Parliament, Article 14/3 requires that:

"Member States shall ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of small-scale biomass boilers and stoves, solar photovoltaic and solar thermal systems, shallow geothermal systems and heat pumps. Those schemes may take into account existing schemes and structures as appropriate, and shall be based on the criteria laid down in Annex IV. Each Member State shall recognise certification awarded by other Member States in accordance with those criteria."

In order to satisfy this requirement, work is currently underway within the UK and in the EU as a whole. In particular there are two initiatives pertinent to Heat Pumps: EUCert & Geotrained. Accordingly this section has been written from today's perspective and will be revised as a priority in 2013.

4.2 Pile Designer (Structural and Geotechnical)

The Pile Designer shall be a geotechnical or civil engineer with a relevant degree qualification. Pile designs shall be signed off by Chartered Engineers with experience in the following areas:

- Pile design to current codes of practice and standards such as BS EN 1997-1:2004 and in London, LDSA GN1¹
- Limit state design, ULS factors of safety and SLS movement effects
- Negative skin friction effects
- Pile axial load and concrete stresses
- Continuous development to be aware of latest developments in thermal pile design

4.3 GSHP Designers

The thermal pile ground heat exchanger shall be designed by competent personnel, where the term "*competent personnel*" shall be deemed to include the following:

- A Chartered Engineer (or EU equivalent qualification), with documented thermal pile ground heat exchanger design experience and who is following a documented Continuing Professional Development pathway in the field of ground source heating and cooling.
- A Chartered Geologist (or EU equivalent qualification), with documented thermal pile ground heat exchanger design experience and who is following a documented Continuing Professional Development pathway in the field of ground source heating and cooling.
- An experienced professional, in the field of engineering, geology, buildings services or physics, with a CV summarising documented design experience of GSHP systems, and is following a documented Continuing Professional Development pathway in the field of ground source heating and cooling.

¹ London District Surveyors Association (2009) Guidance notes for the design of straight shafted bored piles in London Clay, Guidance Note 1.

- Certified Geo-Exchange Designer (CGD) as certified by the Association of Energy Engineers (AEE), with documented thermal pile ground heat exchanger design experience and who is following a documented Continuing Professional Development pathway in the field of ground source heating and cooling.

It is recognised that the design of a thermal pile ground heat exchanger will normally involve competent personnel with more than one specialism and will typically include the involvement of engineering specialists and a geologist.

Trained design personnel shall attain sufficient continuing education points in order to maintain their qualifications in accordance with the certifying body's requirements. Designers whose qualifications lapse for any reason shall regain the qualification in accordance with the certifying body's requirements before continuing with any design services.

4.4 M&E Designer

The M&E Designer should be suitably trained and qualified to deliver the role as described in Section 3.7. M&E Designs should be signed off by people suitably competent to do so, such as Chartered members of a relevant institution, such as the Chartered Institution of Building Services Engineers, the Institution of Mechanical Engineers or the Institution of Engineering and Technology.

4.5 Main Contractor

As the Main Contractor is expected to take the Co-ordinator role, they should be suitably qualified in project management of building and M&E works in order to supervise the installation of the GSHP system and interfaces between various parties.

4.6 Piling Contractor

The piling contractor is responsible for maintaining the integrity of the thermal loops during installation for the duration of the piling works. In this respect, operatives should be trained to a satisfactory level in loop fixing, loop testing, and loop integrity preservation techniques in accordance with the thermal training standards to be adopted by the FPS.

All piling operatives employed on the contract shall hold an appropriate valid and current Construction Skills Certification Scheme (CSCS) card as issued by Construction Skills Certification Scheme Limited or an equivalent body in a state of the European Union.

The Federation of Piling Specialists (www.fps.org.uk) produces detailed documentation, advice and standards on all aspects of piling operations and reference should be made to this website concerning the installation of the piles.

4.7 GSHP Contractor

The GSHP Contractor is responsible for supervising the fixing, installation and to ensure the integrity of the loops during installation of the piles and the header pipe works (and the plant room, which is outside the brief of this document). In this respect, operatives should be trained to a satisfactory level in loop fixing, loop testing, and loop integrity preservation techniques in accordance with the appropriate thermal training standards.

The senior site operative responsible for supervising the Ground Heat Exchanger (GHE) installation shall be experienced or knowledgeable in all aspects of the GHE installation they are supervising which may include piling, flow and pressure testing, electro-fusion techniques, flushing and purging, sterilisation and the addition of thermal transfer fluids. They must also be aware of their statutory

responsibilities and the environmental risks of their operations with emergency planning if necessary as set out in MIS 3005².

All GSHP operatives employed on the contract shall hold an appropriate valid and current Construction Skills Certification Scheme (CSCS) card as issued by Construction Skills Certification Scheme Limited or an equivalent body in a state of the European Union.

The GSHP Contractor should be able to display competency through certified installer training provided by approved bodies.

GSHP Contractors involved in headering, jointing etc. should also have suitable qualifications and experience as described in Section 4.8 below.

4.8 Thermal Loop Fabricators

Thermal loop fabricators shall be fully accredited with Butt Fusion Jointing and/or Electro Fusion of Mains and Services Certificate F/500/6500 (City & Guilds of London) and/or Socket Fusion Jointing or suitable manufacturer's training certification. Fabricators must also be aware of leak risk and that they could be liable if pollution occurs from their defective work (refer to MIS 3005).

Thermal loop fabricators shall ensure that they are fully conversant with current practice at least every five years. Where joint failures occur that are not solely attributable to materials or equipment failure, all persons responsible for the defective work shall attend retraining prior to continuation with fabrication duties.

² DECC (2012) Microgeneration Installation Standard 3005: Requirements for contractors undertaking the design, supply, installation, set to work commissioning and handover of microgeneration heat pump systems, Issue 3.1a.

5.0 DESIGN METHODS & COMPLIANCE

5.1 General GSHP Design Approach

The general design approach is described in Figure 5.1. Thermal pile design is carried out by three main parties, the Pile Designer, the M&E Designer and the GSHP Designer, see Section 3.0 for definitions.

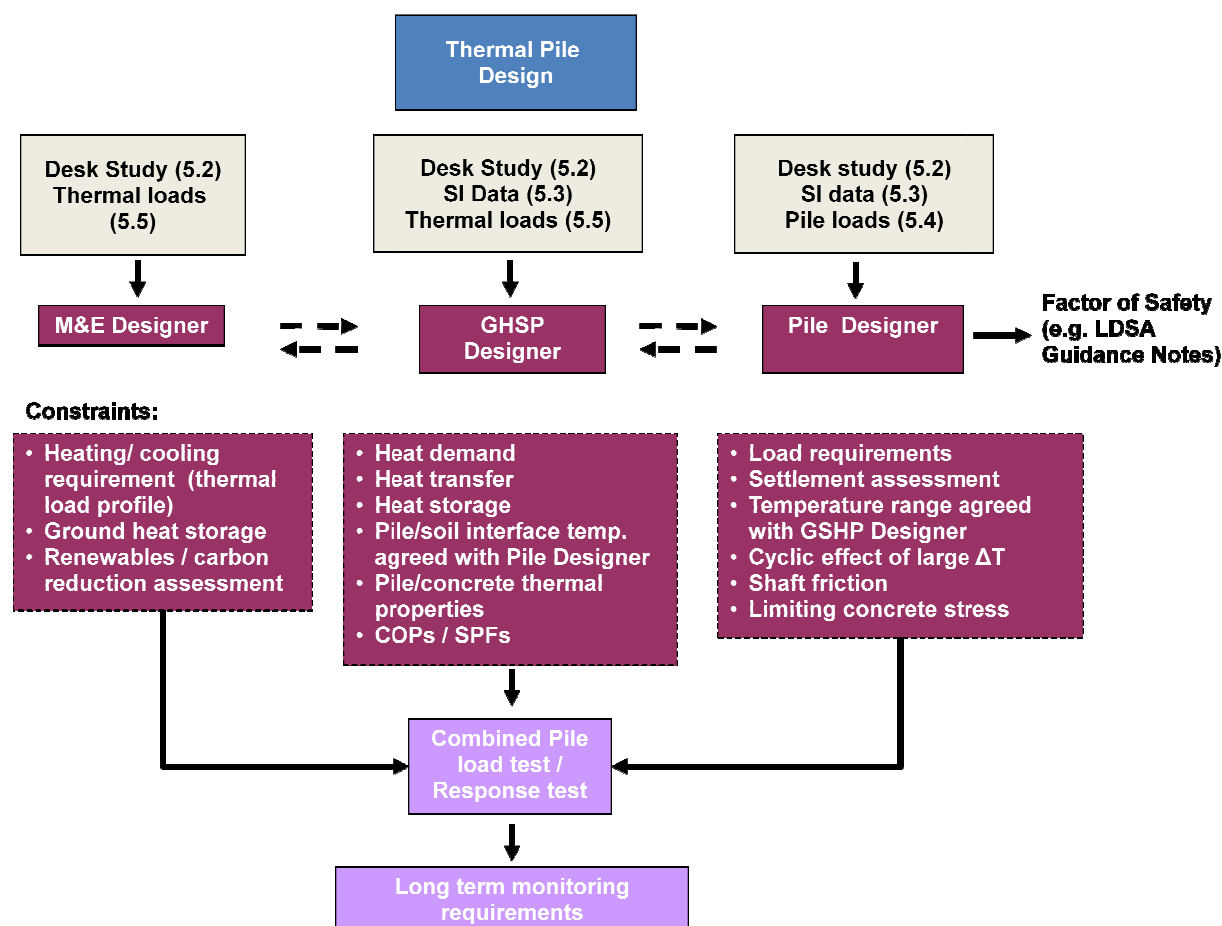


Figure 5.1: General thermal pile design approach

The Pile Designer must ensure that the ground conditions are suitable to carry the structural pile loads, while also considering the thermal effects on the pile performance (refer to Section 5.6). Individual tasks carried out by the Pile Designer are expected to include:

- Desk study to determine the suitability of the site for piled foundations
- Site investigation to provide factual details of soil conditions and interpretation of that data including relevant soil properties
- Assessment of structural loads provided by the Structural Designer
- Pile design for structural loads and a temperature range considering daily and seasonal cyclic effects
- Input into the piling specification including pile testing
- Input into the long term monitoring regime

The M&E Designer's role is to provide information in respect of the building's heating and cooling requirements and in conjunction with the GSHP Designer determine the specific function of the thermal pile circuit for the particular building. Individual tasks carried out by the M&E Designer should include:

- Desk study to determine the heating and cooling loads of the building.
- For complex systems, where a number of heating and cooling processes are necessary to meet M&E requirements or where the ground heat exchanger will be providing a base load for a complex system with additional plant delivering the additional load, the M&E Designer shall estimate the thermal loads to be effected on the pile circuit. This shall include monthly loads (kWh), peak loads (kW) and peak load duration, in order to identify the annual kWh the ground heat exchanger will absorb or deliver. The required load data is outlined in Section 5.5 below.
- Carry out a sensitivity analysis to determine how variations in load profiles affect the performance of the GSHP system.
- Respond to feedback from GSHP Designer in respect of achievable thermal loads on pile circuit and heat pump performance.
- Develop specifications for thermal loops and header pipes.
- Specify performance criteria for the GSHP system (loads, SPFs, load-side temperatures etc.).
- Estimate overall energy and carbon performance for the building which shall comply with relevant building regulations (Part L (England and Wales), Section 6 (Scotland) and Part F (Northern Ireland)). This is different to the modelling carried out to estimate the actual performance of the building in use.

The GSHP Designer's role shall be to determine the heating and cooling potential of the thermal loops and liaise with the M&E Designer regarding how this fits within the overall M&E design for the building. The GSHP Designer shall take into account the ground conditions as well as optimising the thermal loop layout within the piles in order to produce a design appropriate to the specification.

The tasks carried out by the GSHP Designer should include:

- Desk study to determine the suitability of the site for a GSHP system
- Input into site investigation specification to provide details of the thermal properties of the ground
- Assessment of the building thermal loads provided by the M&E Designer
- Design thermal pile loop details and header pipe layout to meet thermal loads defined by the M&E Designer whilst meeting the ground temperature limits agreed with the Pile Designer
- Input into pile specifications and preliminary / contract pile test
- Develop preliminary drawings for pile loops and header pipe layouts for approval with the Pile Designer
- Production of final drawings for pile loop layout and header pipe layouts
- Input into the BMS (refer to Section 3.14 and Section 14.0)

In most cases the pile design and layout will be fixed by the Structural Designer or Pile Designer. The GSHP and M&E Designers shall then, through a process of design and feedback between each other, determine the most appropriate use of thermal piles for the particular building. The optimised use of the thermal piles will be determined by the building's heating and cooling profile, where in some cases such piles could be used for diurnal and seasonal load buffering (i.e. thermal energy storage) and other cases may be the sole ground heat exchanger for a heating only system.

Only suitably trained and competent persons shall carry out the design of a heat pump system (refer to Section 4.0). Each stage of the design is described separately in the following sections.

5.2 Desk Study

At the planning stage of a piling project, desk studies are routinely carried out to determine the constraints and suitability of the site. The purpose and general scope of a desk study is defined in BS5930 (or Eurocode 7 or equivalent). A desk study shall be carried out which shall be appropriate for the scale of the ground heat exchanger to be designed and installed.

The desk study for suitability of a simple pile installation shall cover as a minimum:

- Regulatory requirements
- Geology
- Hydrogeology
- Previous site use
- Potential contamination of ground and/or groundwater
- Potential for unexploded ordnance
- Ground conditions for drilling equipment access
- Underground and overhead services identification and location (including any private water supply or sewerage system)
- Presence of underground tunnelling, mining and quarrying, particularly coal (see Section 2.4 for further details)
- Party wall issues (see Section 2.8 for further details)
- Barriers to construction

In addition, for thermal piles the following should be considered:

- Estimated thermal properties of the ground
- Estimated average undisturbed ground temperature
- Average ambient air temperatures
- Estimated geothermal heat flux
- An estimate of the peak and annual heating and cooling loads by the M&E Designer, usually based on benchmark data rather than any detailed modelling, because it is unlikely that the building design will be sufficiently developed to enable it to be modelled
- The M&E Designer shall also ascertain the carbon reduction requirement and translate this into an estimated heat pump performance requirement

A desk study for complex (larger) GSHP systems (see Figure 5.2) shall contain the above as a minimum, plus:

- Brief impact assessments on the ground e.g. alteration of undisturbed ground temperatures
- Brief impact assessment on aquifers e.g. alteration of ground water temperatures, flow, contamination risk, etc.
- Brief impact assessment on the surrounding area including other geothermal schemes, water abstraction schemes or other environmental receptors such as springs, wetlands, lakes and rivers
- Assessment of the sustainability of the scheme based on annual kWh and peak loads for heating and cooling
- Impact assessment of adjacent infrastructure, such as water supply, wastewater, tunnels etc.

BS5930: 1999 + A2:2010 gives guidance for desk studies (refer to Section 2.10).

Where the desk study includes any outline design works, the specialist shall clearly state what assumptions have been made and which particular elements of the design have been covered.

5.3 Site Investigation

The code of practice for a site investigation is set out in BS5930 / BS EN 1997-2 (refer to Section 2.10). The pile design requires site investigation which should include details on:

- Site stratigraphy
- Strength and stiffness soil properties
- Chemical soil properties
- Water table
- Contamination risk
- Obstructions, existing foundations, services etc.
- Archaeology

The ground heat exchanger design requires additional material properties to be determined. The desk study information should be reviewed and consideration should be given to refine the following parameters by site investigation if cost effective:

- Existing in situ temperature profile over the depth of the pile
- Thermal conductivity and volumetric heat capacity details of the ground based on laboratory tests – see Appendix B
- Thermal conductivity based on thermal response testing
- Permeability of the ground

5.4 Pile Loads

Structural loads from the building should be calculated for each pile by carrying out a load take-down, considering all of the permanent and variable actions and the path through which they are transmitted to the foundations. Standard values for actions on structures (e.g. imposed loads, self weight, wind load, snow load, thermal load, accidental actions) are given in BS EN 1991 (Eurocode 1 – Actions on Structures). This information is usually provided by the Structural Designer to the Pile Designer.

5.5 Thermal (Heating & Cooling) Load Data

A reliable and robust assessment of the building's heating, cooling and hot water requirements shall be made based upon British European Standard (BS EN) 12831 – 2003, current Chartered Institution of Building Services Engineers (CIBSE) guidelines as per Simple Heating Design Guide for 45 kW_{th} or under, and CIBSE Guide A for small commercial applications of 45 kW_{th} and under.

The procedure to be followed in determining the thermal loads depends on the complexity of the system. Details of the differences between simplified and complex GSHP systems are given in Figure 5.2.

Large or complex buildings shall be modelled by development of a Dynamic Simulation Model (DSM). The DSM shall provide peak load, peak load duration and an annual profile of monthly load data as indicated in Figure 5.3 below. Sufficient sensitivity analysis shall be carried out to ensure that variations in daily cycles are included in the design e.g. winter day peak heating load versus summer day peak cooling load. For systems less than 45 kW_{th} other approved software (MIS3005) may be used to produce estimates of the thermal loads for use within the GSHP system design by the M&E and GSHP Designers.

In buildings with a number of integrated systems and where the GSHP system is providing a base load, hourly load data may be desirable in order to better understand the peaks and troughs of the load demand on the GSHP system. However, where the annual load data is calculated for a time period resolution shorter than monthly, consideration shall be taken for the inherent weaknesses in using a short time period resolution, as modelling errors can become significant.

Building heating, cooling and hot water loads shall be appropriate to building type, location, orientation, use and occupancy, e.g. modern school, closed in August.

The proportion of the M&E Designer's space heating/cooling or hot water that is expected to be provided by the heat pump system annually shall be stated by the designer. An understanding of the proportion of the heating, cooling & hot water demand which will be met by the heat pump system shall be demonstrated.

The Government's Standard Assessment Procedure for the Energy Rating of Dwellings (SAP) is a mandatory annual energy assessment tool used to demonstrate compliance with building regulations for dwellings - Part L (England and Wales), Section 6 (Scotland) and Part F (Northern Ireland). However, this does not provide the monthly or peak load information and shall not be used to size GSHP systems. If SAP is used to provide annual kWh for a simplified system then a further calculation shall be carried out in order to ascertain the peak load for equipment and ground heat exchanger sizing (refer to MIS 3005¹).

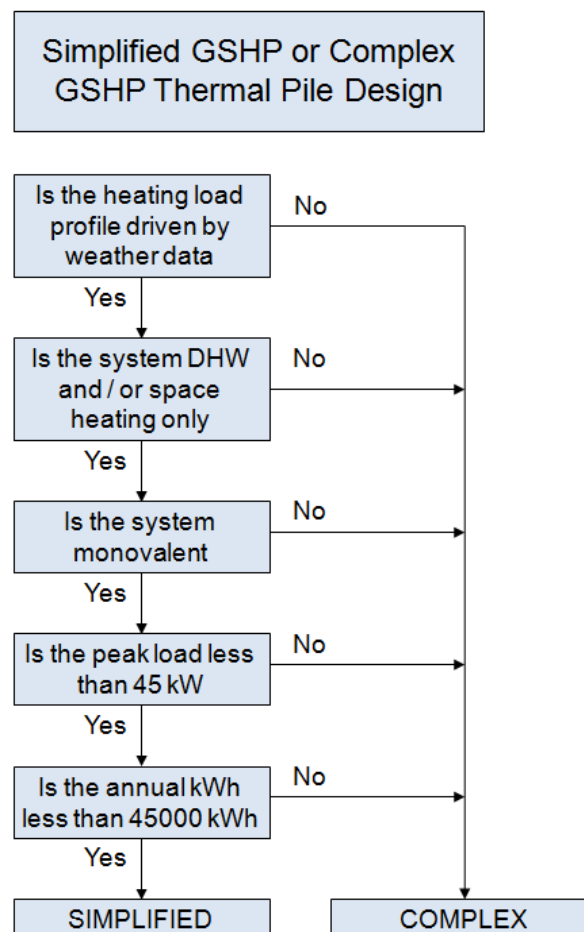


Figure 5.2: Simplified or complex system decision tree

¹ DECC (2012) Microgeneration Installation Standard 3005: Requirements for contractors undertaking the design, supply, installation, set to work commissioning and handover of microgeneration heat pump systems, Issue 3.1a

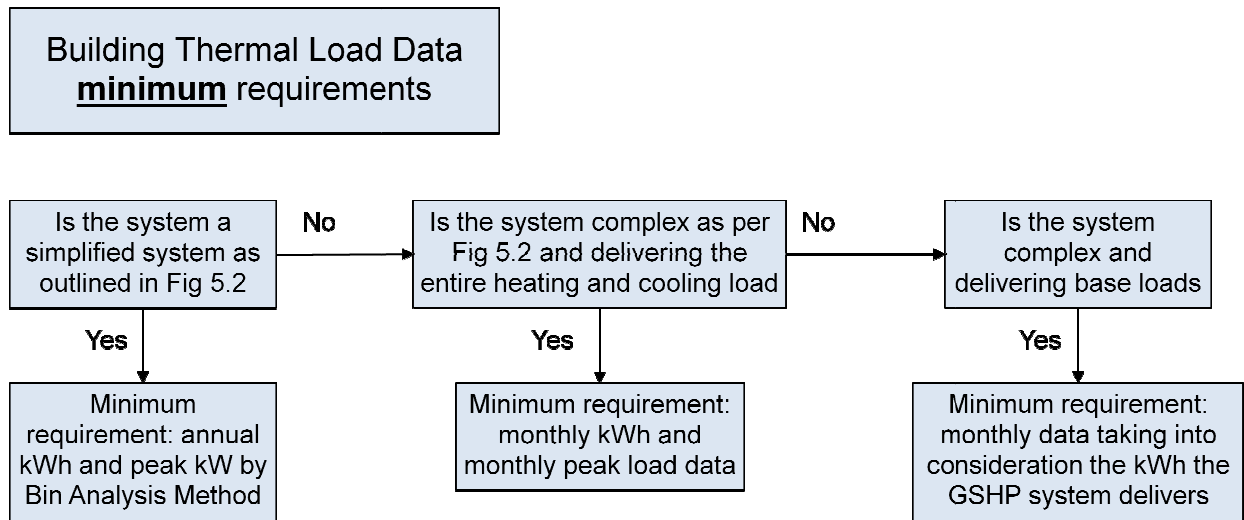


Figure 5.3: Minimum building thermal load data requirements decision tree

Simplified Building Energy Model (SBEM) shall not be used to size GSHP systems, however it is a commonly used compliance tool to ascertain an annual energy assessment. SBEM does not provide peak load data and a further calculation is required in order to ascertain the peak load for equipment and ground heat exchanger sizing.

5.6 Pile Design

The design of thermal piles requires consideration above and beyond the usual pile design process (following BS 8004 or BS EN 1997-1 limit state design approach). The aim of the pile design should be to quantify the thermal loads and then apply factors of safety currently used in the normal pile designs. It is not planned to vary the factors of safety.

Figure 5.4 shows the additional considerations that should be taken into account when designing thermal piles.

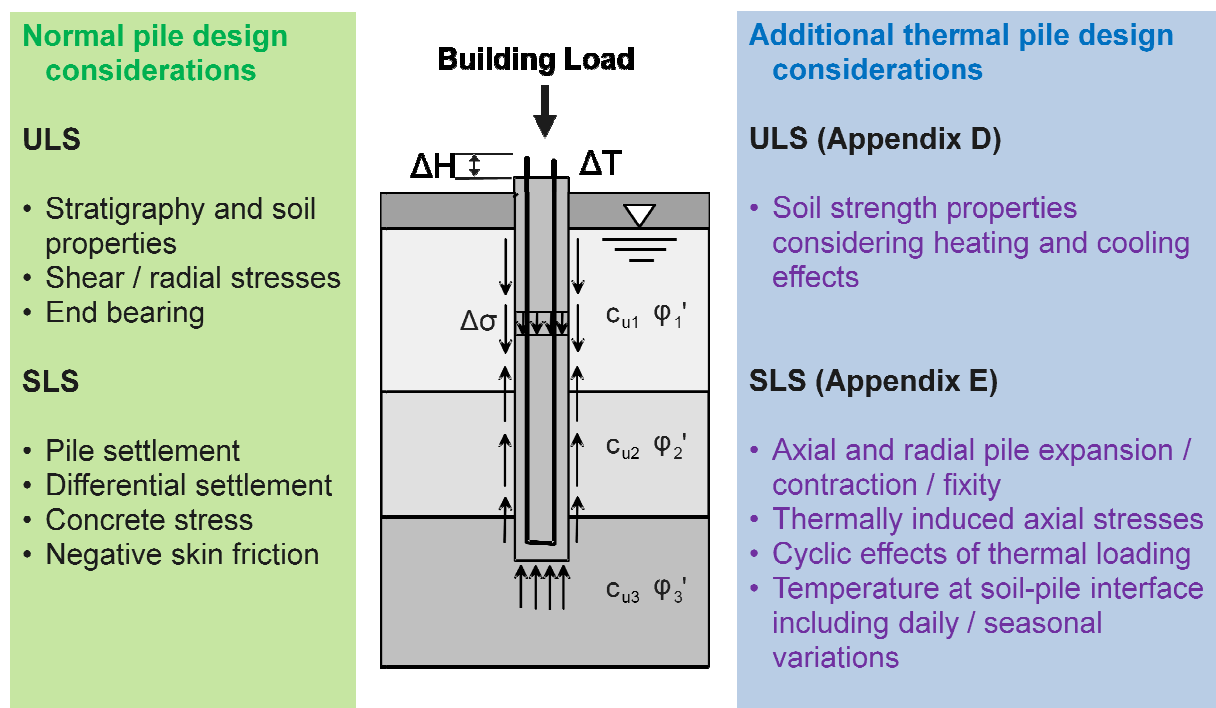


Figure 5.4: Additional considerations for geotechnical design of thermal piles

5.6.1 Limit States

Ultimate limit state (ULS) The ULS concerns the geotechnical axial load capacity of the pile compared to the applied pile load. The ultimate pile capacity occurs when the pile has reached large values of displacement, typically taken to be >10% of the pile diameter although there are a variety of definitions. Consideration should be given to the change in soil properties caused by heating and cooling.

Serviceability Limit State (SLS) This concerns the pile settlement and structural performance at design loads. Consideration should also be given to the thermal expansion and contraction of the pile caused by heating and cooling.

5.6.2 Thermal Effects on Soil Parameters and Pore Pressures

Piles are typically 10 to 50m long. Based on mean air temperatures the typical temperature in UK soils and rocks varies from 8.5°C in NE Scotland to 11.3°C near London, (refer to MCS 022²). This can be influenced by urban heat islands such as for London.

The heating of medium dense to dense non-cohesive soils around a thermal pile is not expected to have a significant effect. However, the heating of fine grained soils may change the soil properties such as preconsolidation pressure, stiffness and strength. The change in soil parameters, especially near the soil-pile interface, is not fully understood. However, excess porewater pressure is expected to develop by heating due to relatively large thermal expansion of pore fluid compared to the thermal expansion of soil skeleton. A preliminary estimate of the change in undrained strength of cohesive soils by heating should be made based on the ground temperatures expected. With time, consolidation and dissipation of the excess porewater pressure produced by heating the soil will occur and lead to an increase in soil strength. A summary of current knowledge on the effect of heating on the properties of cohesive soils is given in Appendix C. The effect on horizontal earth pressures and settlements should be considered.

In pile design, normally consolidated fine grained soils are considered to apply negative skin friction to the pile design where changes in the loading to the soil will lead to further consolidation. When the soil is heated, the preconsolidation pressure is reduced, and additional settlements are generated, making it important to include the possible effect of negative skin friction in such soils. In heavily overconsolidated fine grained soils, the effect of preconsolidation reduction is small. The soil skeleton will tend to expand by heating and hence small heave movements are expected to occur.

5.6.3 ULS Design Considerations

At the ultimate limit state for externally applied loads, shaft friction on the soil-pile interface is fully mobilised along the full length of the pile in one direction only, and the base capacity is fully mobilised. For thermal piles, the thermal strains are small and are not expected to affect the ULS, which is typically assessed as when the pile has settled by 10% of the pile diameter in a compression load test. The ultimate limit state must then be reassessed, after considering the effects of heating and cooling on the soil parameters, using the approach set out in current design standards such as partial factors e.g. BS EN 1997-1:2004 or a lumped factor of safety e.g. LDSA GN1³.

In normally consolidated soft clays, large settlements can occur due to applied and thermal loading. Appropriate allowance should be made for the settlements inducing negative skin friction (Q_n) on the

² DECC (2011) MCS 022: Ground Heat Exchanger Look-Up Tables, Supplementary Material to MIS 3005.

³ London District Surveyors Association (2009) Guidance notes for the design of straight shafted bored piles in London Clay, Guidance Note 1.

piles. Methods of calculating the downdrag for applied loads are provided by Fellenius⁴ and Poulos⁵. Similar methods for assessing thermally induced downdrag should be adopted in ULS calculations in soft clays where large settlements may cause the ULS condition to be reached.

5.6.4 SLS Design Considerations

The serviceability limit state should be assessed for the movements expected to occur under both externally applied and thermal loads. The thermal movements mobilise pile shaft friction and end bearing which can change the axial stresses in the pile and cause additional settlement due to the downdrag/negative skin friction effects (refer to Poulos⁵ with mechanisms described in Appendix D and SLS effects described in Appendix E). Also, the combined stress from the pile load and the thermal load should not exceed the maximum allowable material stress within the pile.

The uniqueness of thermal stress effect is that, if the pile is constrained by the ends or by high shaft friction, the internal stress will be large but the settlement or heave will be small. If the pile is less constrained, the internal stress is small but the settlement or heave will be larger. This counteracting mechanism needs to be understood before evaluating the pile performance during GSHP operations.

If the thermal pile is responding in undrained conditions, the SLS can be assessed using conventional ratios of stiffness to undrained strength making allowance for the reduced undrained strength. If the thermal pile is responding in drained conditions, the SLS can be assessed using drained parameters and considering possible change in radial stress due to changes in soil properties. This can be calculated using cavity expansion theory combined with the coefficient of thermal expansion for the pile.

In overconsolidated clays the settlements are smaller than for normally consolidated clays, and are incorporated into the SLS calculation of the building movements.

The effect of thermal cyclic loading on the SLS should also be considered.

Radial expansion and contraction of piles may occur due to heating and cooling, respectively. For large diameter piles, the radial displacements can be large. Hence, the radial soil stress acting on the pile may change, leading to change in shaft resistance characteristics.

Considerations beyond those for typical pile design include (refer to Appendix E for further details):

- Pile head fixity and thermal expansion / contraction movements of the pile both in axial and radial directions.
- Thermally induced axial stresses within the concrete in the piles.
- Cyclic effects of thermal loading.
- The temperature at the pile soil interface, including daily and seasonal variations, ensuring that the soil-pile interface does not freeze. It is difficult to assess the effects of ice wedging on shaft friction. Examples of ground freezing effects are described in Brandl⁶.

5.6.5 Quantification of Thermal Effects

The thermal effects on the pile design can be assessed by the following methods:

⁴ Fellenius, B.H. (2006) Results from long term measurements in piles of drag load and downdrag, Canadian Geotechnical Journal, 43 (4), 409-430.

⁵ Poulos, H.G. (2008) A practical design approach for piles with negative friction, Proceedings of the ICE: Geotechnical Engineering 161, Issue GE1, 19-27.

⁶ Brandl, H. (2006) Energy foundations and other thermo-active ground structures, Geotechnique, 56 (2), 81–122.

Computer model	Computer software (e.g. Oasys PILE, Thermopile, Cambridge energy piles software) can be used to model piles subjected to structural and thermal loads. Alternatively thermo-hydro-mechanical (THM) finite element programs can be used (e.g. LS-Dyna).
Pile load test	Full scale instrumented pile tests can be carried out which combine static loading and thermal response test, e.g. Amis et al. ⁷ and Bourne-Webb et al. ⁸ Alternatively the thermal response test could be carried out on a reaction pile for the load test.
Design charts	Empirical charts are provided in Appendix F based on a straight shafted pile at a typical central London site (London Clay over the whole length of the pile) using <i>Oasys Pile</i> and Cambridge energy piles software, calibrated first against results obtained from Lambeth College.

5.7 GSHP Design

5.7.1 Overall System Performance

In order to maximise the performance (i.e. SPF) of the thermal pile system the GSHP Designer will need to liaise with the M&E Designer and the Pile Designer in order to ensure that:

- The maximum and minimum temperatures are defined.
- The daily and seasonal cyclic temperature changes are agreed.
- The distribution temperature to the building should be as low as practically possible in heating and as high as practically possible in cooling.
- The system should be sustainable in the long term, i.e. the temperature within the thermal loop should not exceed the design conditions during the design life of the system. Inherently, reasonably balanced systems such as heating and cooling systems are more efficient than heating only / cooling only systems where natural recharge is relied upon.
- The electrical energy used in circulation is minimised (refer to Section 7.6).
- The design has sufficient redundancy to allow for construction and system performance issues. This redundancy needs to be addressed within the project team for the overall project rather than party by party. Factors contributing to decisions on redundancy include:
 - Piling technique
 - Likelihood of damage to loop installation during piling, trimming and headering
 - Uncertainty in thermal properties and analysis technique
 - Proportion of piles with thermal loops

5.7.2 General Considerations

The design of the ground heat exchanger shall be in compliance with the heat pump manufacturer's specification and operating parameters of the heat pump and shall be clearly documented so that such compliance may be demonstrated.

⁷ Amis, T., Bourne-Webb, P., Davidson, C., Amatya, B. And Soga, K. (2008) The Effects of Heating and Cooling Energy Piles Under Working load at Lambeth College, UK, DFI Conference, New York.

⁸ Bourne-Webb P., Amatya, B., Soga, K., Amis, T., Davidson, C. and Payne, P. (2009) Energy pile test at Lambeth College, London: geotechnical and thermodynamic aspects of pile response to heat cycles, *Geotechnique* 59 (3), 237–248.

Detailed pile heat exchanger design incorporates the loop design (i.e. the number and spacing of heat exchange pipes in the pile cross section), any additional concrete requirements, header pipe work design, trench requirements and backfill, header valve chambers or valve vaults up to the building interface. The GSHP Designer will need to work with the Pile Designer and the Pile Contractor to ensure that the loop design is buildable and compatible with the construction process.

The GSHP design scope should be further extended to include as a minimum: agreement of the building penetration, internal piping, pressurisation requirements, monitoring and Building Management Systems (BMS), monitoring requirements and circulation pump sizing. The specific standards relating to such an extension of the scope of design are not covered by this document and further guidance as required, shall be sought.

In cases where a competent specialist is either (a) providing a provisional or preliminary design, before all relevant building constraints have been identified or (b) providing a specific input to a complete ground heat exchanger design process, the specialist should clearly identify which elements of the design are covered and any assumptions that have been made by the specialist regarding other elements of the overall design.

The design of the ground heat exchanger system shall take into consideration; heat pump performance including minimum coefficient of performance (COP) requirements, fluid temperature constraints, geology, the thermal conductivity of the ground and concrete, flow rate, loop configuration and its hydraulic implications, local climate and landscaping.

Data obtained during the desk study and/or thermal response test (TRT) shall be used with appropriate design software for ground heat exchanger sizing. For larger and more complex heating and cooling systems, more appropriate ground models shall be used to prove the heat exchanger system design is viable in the longer term.

For complex systems and where the ground heat exchanger will be providing a base load with additional plant delivering the additional load, the minimum building thermal load data requirements are for an annual profile of monthly kWh_{th} of heating and cooling along with peak load for each month and the maximum duration of the peak load per month in order to identify the annual kWh_{th} the ground heat exchanger will absorb or deliver. The required load data is outlined in Section 5.5 above.

The design of a system shall take into account specific ground conditions that may affect the integrity or performance of the heat exchanger. The Environment Agency should be contacted if a scheme is to be installed in land affected by contamination and care shall be taken not to compromise ground contamination remediation measures (e.g. capping layers). Backfilling shall be carried out to ensure no pathways for the migration of groundwater or ground contamination are created. The Environment Agency shall if necessary be consulted for guidance relating to the risk assessment procedure appropriate to the system being designed. Refer to the checklists in EA, 2011⁹ to determine environmental risks from your proposed design. Steps must also be taken to ensure prevention of the migration of gases (e.g. radon or methane) into a building. Early consultation is advised.

5.7.3 Specific Thermal Pile Design Considerations

Thermal piles are different from borehole heat exchangers in a number of important respects and it is important that these are accounted for in the design.

1. The layout of thermal piles is usually fixed by the structural/geotechnical design. This means that the GSHP Designer is often aiming to optimise the use of the thermal piles for a given building rather than ensuring all the heating and cooling requirements are met.

⁹ Environment Agency (2011) Environmental good practice guide for ground source heating and cooling.

2. The thermal piles also provide essential structural support to the building. Consequently the temperature limits within which the pile heat exchangers operate must be agreed with the Pile Designer. In particular it is essential to ensure that the ground must not freeze. This can be achieved in one of two ways. The simplest and most conservative way is to specify a minimum flow temperature at the heat pump of +2°C allowing for a tolerance of $\pm 2^\circ\text{C}$. However, this is unlikely to lead to optimal thermal design and in practice lower temperatures can be achieved due to the transient thermal buffering offered by the pile concrete. In order to accept lower temperatures, analysis must demonstrate that for the planned operation of the heat exchanger system, temperatures at the concrete-soil interface will not fall below zero degrees Celsius. Further discussion of appropriate temperature limits and monitoring is given in Section 14.0 and Appendix A.
3. Thermal piles tend to be both significantly shorter and of larger diameter than borehole heat exchangers. These geometric differences mean that (1) for short time step analysis it is important to take into account the actual size and shape of the heat exchanger, and (2) for long term analysis the short length should be considered in a 3D analytical or numerical model.
4. The large volume of concrete in the pile cross section, combined with generally 50mm offset of the heat exchange pipes from the ground means that the resistance of thermal piles can be significantly greater than that of borehole heat exchangers, depending on the number of pipes installed.
5. Especially for CFA piles with centrally placed loops, the thermal storage capacity of the piles themselves may be an important contributor to the thermal efficiency of the scheme.
6. It is common to connect a number of different thermal piles together into a single pipe circuit. This can affect the heat transfer characteristics of individual pile heat exchangers and can also lead to more variable temperature fields developing in the ground.

5.7.4 Design Parameters

The initial ground temperature and thermal conductivity should be determined in situ using a thermal response test where practicable. For smaller schemes this may not be economic, in which case in situ temperature profiling during the site investigation combined with laboratory testing for thermal conductivity would be recommended. If the local thermal conditions are well known then it may be possible to proceed on the basis of a literature review only, but this should be verified by subsequent assessment of the system performance.

Thermal diffusivity of the ground is also a required design parameter. This is often calculated based on the thermal resistance and the volumetric heat capacity. The latter is difficult to determine by laboratory testing and assumed values are often taken. Alternatively the volumetric heat capacity may be calculated based on the phase proportions of the soil as described in Appendix B.

Pile thermal resistance is best determined numerically due to the complex geometry of the heat exchanger. Alternatively, some guidance is given in the SIA document D0190¹⁰. Care must be taken for larger diameter piles with large thermal resistance as these may not be at steady state and hence a constant value of thermal resistance may not always be appropriate. The thermal storage capacity of the concrete in such cases may be significant.

5.8 Floor Slab Construction

Consideration should be given to the following issues when deciding where to place header pipes in the floor slab:

¹⁰ SIA Documentation D 0190 (2005) Utilisation de la chaleur du sol par des ouvrages de fondation et de soutènement en béton.

- Prevention of condensation on floor slabs above header pipes
- Insulation use where pipes are placed at shallow depth
- Header pipes should be designed for head loss minimisation
- Structural impact of header pipes on slab design
- Integration of header pipes with other services to avoid conflicts

5.9 Results of System Design Calculation

Results of system design calculation shall be reported to the client outlining the anticipated sustainability and design life of the system. Commercially available software programmes shall be used for complex designs and details of how the software output is calculated should be available from the software distributor.

6.0 THERMAL RESPONSE TESTING

6.1 Aim of the Test

Thermal Response Testing is carried out to provide accurate information about the thermal properties of the ground where thermal piles are being constructed in order to enable the GSHP Designer to optimise the energy exchange for a specific installation. For small schemes it may not be economic to carry out a test compared to adopting conservative thermal properties during design. However, for larger schemes, or in situations where there is uncertainty regarding the in situ thermal properties then it is recommended that a thermal response test is carried out. Using test measured thermal conductivity increases the thermal loop thermal modelling precision and therefore assists with optimising the running efficiency of the heat pump system.

For thermal piles it is also desirable to gain an understanding of how the pile will respond structurally and geotechnically to the thermal changes imposed on it during operation. This can be achieved by extending the scope of a thermal response test to include measurement of strain and temperature within the pile over a heating and cooling cycle.

6.2 Testing Strategy

As piles have a larger diameter and hence a greater heat storage capacity than borehole heat exchangers, it is not always possible to carry out thermal response test directly on a thermal pile heat exchanger within an economic timescale. Consequently the following options are recommended:

1. Where the potential for use of thermal piles have been identified at an early stage, a site investigation borehole may be equipped with a single U-tube and used to carry out a thermal response test. This will allow determination of the ground thermal properties. Refer to Section 6.3 for further details.
2. Where the thermal piles are to be no greater than 300mm in diameter then a thermal response test may be carried out using the pile, adopting the same methods as for a borehole heat exchanger. Refer to Section 6.4 for further details.
3. Where the thermal piles to be constructed are larger than 300mm in diameter then a bespoke thermal test, likely to be of greater duration and requiring more sophisticated interpretation techniques can be carried out. Refer to Section 6.5 for further details. Alternatively, a borehole can be tested at site investigation stage as indicated above.
4. Pile thermal load test. To determine the stress-strain behaviour of a pile during heating and cooling one of the test types above could be extended to include both heat injection and heat rejection to the pile while it is maintained under load. Monitoring of the temperatures and strain developed within the pile itself then allows assessment of the stress-strain response of the pile as well as its thermal characteristics. Refer to Section 6.6 below for further details.

Where thermal response testing is carried out in a thermal pile it is recommended to do so in a preliminary test pile if possible. This provides time in the construction programme to allow for the pile to reach equilibrium with the surrounding ground temperature before testing and also allows time for the findings of the test to be incorporated into the design.

If a working (or contract) pile is to be subject to a thermal response test then it may not be possible for any assessments of the stress-strain behaviour to be incorporated into the design of the structure. Thermal properties may still be incorporated into the assessment of heating and cooling capacity at this stage.

6.3 Borehole Thermal Response Test

Borehole thermal response tests should be conducted in accordance with the procedure set out in Section 5 of the GSHPA Vertical Borehole Standard¹ and European Committee for Standardization document TC 341 WI 00341067.6 (submitted to CEN Enquiry) prepared by CEN/TC 341 'Geotechnical Investigation and Testing'. The test hole should comprise a U-bend pipe grouted in a borehole no larger than 200mm diameter with high thermal conductivity grout. Heated water is pumped through the thermal loop under turbulent flow and feed and return temperatures are monitored over a specified duration in order to determine the thermal properties of the soil.

Key determinants of the test are:

- Average undisturbed formation temperature
- Average ground thermal conductivity

With additional knowledge of the geology, other parameters such as specific heat capacity can be derived from other tests and/ or published values. Density would also be determined from other site investigation work. These parameters along with the test derived thermal conductivity can be used to calculate the ground thermal diffusivity.

In order to use the information from a borehole TRT in the design of thermal piles, the depth range over which the test is carried out should be similar to the depth of the proposed piles. If the piles are to have a cut off level below the existing ground level then it may be necessary to insulate the top section of the borehole which is above the cut off level, such that this does not affect the test result. If the thermal piles are likely to be of varying length then the GSHP Designer will need to make a judgement about an appropriate test depth and range, or if the pile length variation crosses geological boundaries, then consideration should be given to conducting more than one test in boreholes of different depths.

As thermal piles are typically much shorter than boreholes greater consideration must be given to the surface effects of heat loss from the thermal pile and also the above ground test equipment. The heat injection creates a thermal funnel effect around the pile, where isotherms are significantly curved at the ground surface due to the effect of this boundary. This effect results in increased error within the accuracy of the calculated thermal conductivity. Test methods must also be employed to determine the extent of the heat loss from the above surface test apparatus, so this can then be accounted for in the calculations.

It is also possible to use borehole thermal response tests to determine the borehole thermal resistance. This interpretation is not necessary in this case as the thermal piles will have a different thermal resistance.

6.4 Pile Thermal Response Test (Up to 300mm Diameter)

Due to cost and time constraints it is only practicable to physically test thermal piles up to 300mm diameter. Such tests are closely allied to the common borehole TRT except the pile itself is considered to be the borehole thermal resistance element.

Key determinants of the test are:

- Average undisturbed formation temperature if required
- Thermal conductivity
- Pile thermal resistance (calculated with additional knowledge of the soil density and specific heat capacity)

¹ GSHPA (2011) Closed-loop Vertical Borehole: Design, Installation & Materials Standards, Issue 1.0.

This test is therefore broadly as detailed in Section 5 of the GSHPA Vertical Borehole Standard with the exceptions and variations described in the following paragraphs.

The test duration shall be extended to allow the thermal resistance of the pile to be overcome and evaluated, and thereafter to allow an accurate measurement of the thermal properties of the ground. Consideration should be given to installing a thermistor and strain gauge array within the pile, with thermistors attached to a lantern detail to allow temperatures at the soil/pile interface to be measured together with temperatures and strains within the pile.

Unless the average undisturbed formation temperature is understood, the test should not be started until at least 21 days after the concrete has been poured to allow the pile temperature to reach equilibrium with the standing temperature of the ground. It may be possible to use a shorter wait period if thermistors are cast into the concrete or thermal dip meter readings are taken in the thermal loop at a depth greater than the zone of daily temperature fluctuation (approximately 5m depth). For practical purposes, temperature equilibrium may be assumed to have been reached when a series of 3 sequential daily temperature readings show a maximum of 0.5°C difference.

The thermal response test shall be initiated without heating elements switched on. The temperature measurement shall be logged as the liquid enters and exits the loop, immediately after start-up and for a minimum of 60 minutes, or until equilibrium has been reached within a tolerance of 0.3 °C.

Testing shall comprise the application of controlled heat to the closed-loop for the duration of the test. Specific requirements for the monitoring and provision of heat and power to the circulated fluid are that:

- The collected data shall be analysed using either the following methods as appropriate:
 - Line source method
 - Cylindrical heat source method
 - Numerical algorithms
- If the test is interrupted during the heating period or needs to be retested, a re-stabilisation period shall be allowed before a further test is conducted. The re-test shall not begin until the thermal loop temperature has returned to within 0.3°C of the average undisturbed temperature of the thermal pile at the commencement of the test (ASHRAE²).
- The results of the test shall be analysed by personnel fully conversant and trained in the line source analysis method with suitable qualifications (Section 4.0).

6.5 Pile Thermal Response Test (Greater than 300mm Diameter)

In most cases, for piles above 300mm diameter, either a standard TRT should be carried out in a traditional borehole of appropriate length (see Section 6.4), or data from a detailed desk study of the geology, hydrogeology & thermogeology augmented by site sample testing should be used. In such cases, post installation monitoring should always be used to refine the design and confirm the assumptions used by the designer especially if no in situ TRT has been conducted.

Alternatively, if economically viable on a large scheme, bespoke pile thermal response testing may be carried out.

6.5.1 Bespoke Pile TRT (greater than 300mm diameter)

For large schemes where it may be considered beneficial to test the thermal behaviour in situ then larger diameter piles may be subject to a thermal response test, providing that the test duration can be extended sufficiently to allow the thermal resistance of the pile to be overcome. This should generally

² ASHRAE Handbook (2011) HVAC Applications, SI Edition, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

be regarded as a bespoke test, where the method is to be developed according to the piles to be tested and the proposed interpretation technique. Greatly extended test times could be required, as it is generally recommended that for times less than t_1 the initial test data should be discarded when using line source interpretation methods.

$$t_1 = \frac{5 r_0^2}{\alpha}$$

Where: r_0 = pile radius (m)

α = thermal diffusivity (m^2/s)

Other interpretation methods may allow the testing time to be reduced, but this would need to be demonstrated for the situation being considered.

6.5.2 Large Diameter Piles with Centrally Placed Loops

For the special case of large diameter ($>1000\text{mm}$) piles where the thermal loops are placed in the centre of the pile, then a standard thermal response test, as described in Section 5 of the GSHPA Vertical Borehole Standard, can be utilised to measure the thermal conductivity of the concrete rather than the ground. This may be useful in determining both the thermal resistance of the pile and any contribution which the pile makes to diurnal heat storage.

It is important that such thermal response tests are not used directly to determine the thermal resistance of the pile as a steady state will not have been reached within the timescale of the test and hence any results would be erroneous.

6.6 Pile Thermal Load Test with Strain Measurement

A fully instrumented load test (e.g. Lambeth College³) on a thermal pile will provide the most precise and realistic data for both the geotechnical and thermal design of thermal piles, but will probably only be economically justified on large schemes. Strain gauges and temperature gauges positioned down the length of the pile can be used to show the combined effect of applied load with heating and cooling cycles on shaft friction, axial force and pile head movement. The test pile diameter and materials used should be similar to the proposed thermal piles so that the interface effects at the soil/pile boundary can be accounted for. An appropriate period of monitoring, sufficient for monitoring intended temperature variations similar to that of the proposed scheme is recommended, so that the long term performance of the pile can be assessed rather than the short term effects that would be produced by a rapid load test with extreme temperature fluctuations. Instrumentation types (including strain gauges, thermistors, piezometers etc.) and positions should be chosen to ensure that sufficient data is available for back analysis of the pile test.

³ Bourne-Webb, P. J., Amatya, B., Soga, K., Amis, T., Davidson, T. & Payne, P. (2009) Energy pile test at Lambeth College, London: geotechnical and thermodynamic aspects of pile response to heat cycles, *Geotechnique*, 59 (3), 237-248.

7.0 THERMAL LOOP & JOINTING: METHODS & MATERIALS

Due to the nature of a thermal pile installation e.g. lack of access and long design life, a very high level of quality and durability of all ground heat exchanger components is required.

This section is purely related to the material specification and manufacturer testing requirements and does not relate to the testing requirements for the materials once installed in the ground.

7.1 Pipe Materials & Tolerances

Each thermal loop shall have sufficient markings on the pipe to identify the material, dimensional properties, supplier's name and production period codes.

The manufacturer shall warrant that the pipe is extruded from verifiable virgin grade raw material from a certified producer of PE pipe materials, complying with the relevant standards as follows:

- PE100 DIN 8074/8075 or BS EN 12201 Part 3. **In addition, slow crack growth resistance of greater than 500 hours measured at a pressure of 9.2 bar and temperature of 80°C.**

Note: not all PE100 pipe will meet the slow crack growth resistance of greater than 500 hours and this shall be checked with the pipe supplier/manufacturer.

- PE100RC DIN PAS 1075.
- PE-Xa DIN 16892/16893.

Pipe shall be manufactured to outside diameters, wall thickness and respective tolerance as specified in BS EN 12201 part 2.

In thermal pile reinforcement cages, PE-Xa pipe may allow tighter bend radii to be achieved compared with PE100 pipe and jointing of the pipe within the pile may not be necessary. Table 7.1 shows minimum bend radii according to the German technical standard DVGW W-400¹; however the pipe manufacturer shall be consulted regarding minimum bending radii specific to the pipe they provide.

Installation temperature (°C)	Minimum bending radius PE100 / PE100RC pipe (d: external pipe diameter)	Minimum bending radius PE-Xa pipe (d: external pipe diameter)
20	20 x d	10 x d
10	35 x d	15 x d
0	50 x d	25 x d

Table 7.1: Thermal loop minimum bend radii

7.2 Fusion Processes

All underground piping shall be joined with heat fusion where the fusion fitting and pipe form a homogenous pipe assembly. Acceptable methods of fusion are electro-fusion, butt fusion and socket fusion. Fusion processes shall be carried out strictly in accordance with the manufacturer's instructions and procedures and by suitably trained personnel as outlined in Section 4.7 and 4.8. The GSHP Contractor shall be responsible for providing appropriate measures for dealing with inclement weather when carrying out fusion connection processes.

¹ DVGW W 400-2 Technische Regeln Wasserverteilungsanlagen (TRWW) - Teil 2: Bau und Prüfung; Arbeitsblatt.

7.2.1 *Electro-Fusion Fittings: Materials & Tolerances*

The acceptable material for the ground heat exchanger fittings shall be the same as for the pipe (refer to Section 7.1).

7.2.2 *Butt-Fusion Fittings: Materials & Tolerances*

The acceptable material for ground heat exchanger fittings shall be the same as for the pipe (refer to Section 7.1).

7.2.3 *Socket-Fusion Fittings: Materials & Tolerances*

The acceptable material for the ground heat exchanger fittings shall be the same as for the pipe (refer to Section 7.1).

7.3 **Mechanical Fittings**

For PE-Xa pipes, permanent mechanical fittings (without O-rings) can be used in the thermal pile and header pipe connections. When installed underground, self-amalgamating tape shall enclose the fittings. All other types of mechanical and compression connections shall be accessible for future maintenance, removal and replacement.

7.4 **Specific Pipe Application & Dimensional Specification**

All fittings and pipe shall have specified pressure ratings including any assembly of individual components used to manufacture a sub-assembly for a ground heat exchanger.

External pipe diameters between 20mm and up to 90mm and any pipe diameter utilised as a thermal pile heat exchanger shall be manufactured with minimum pressure rating of 16 bar with standard dimension ratio (SDR) of 11.

External Pipe diameters larger than 90mm shall be manufactured with minimum pressure rating of 10 bar (SDR 17) unless used in a thermal pile which shall then be 16 bar with SDR of 11.

7.5 **Off Site Factory Manufacture & Quality Control**

Where used instead of plain pipe i.e. where the manufacturers specified bend radius for the pipe at the pile foot cannot be achieved, thermal pile u-bend loops shall be factory manufactured under controlled and quality assured conditions by BS-EN-ISO 9001² certified manufacturers. The loop shall be manufactured from pipe conforming in every way with these standards and shall have a purpose-manufactured u-bend fusion-welded to each leg of the pipe. The maximum number of welds to form the u-bend shall be two welds, where each pipe is attached to the u-bend.

Each loop shall be hydraulically pressure tested by the loop manufacturer in accordance with The Pressure Equipment Regulations, 1999³ and at 150% of the working pressure rating of the pipe.

Each loop shall have metre marks identifying the length of the loop commencing with zero at the u-bend in order to verify the installed depth from surface.

The manufacturer/supplier shall warrant that all thermal loops are manufactured in compliance with the above standards.

² British Standards Institution (2008) Quality Management.

³ Legislation.gov.uk (1999) The Pressure Equipment Regulations.

7.6 Pipe & Fittings Sizing

Pipe and fittings shall be sized in order to maintain efficient heat transfer in the ground heat exchanger. Thermal loops shall be sized to ensure turbulent flow with a **minimum** Reynolds number of 2,500 at peak load (coldest fluid temperature) and design flow rate conditions (this may not apply in the case of modulating or dynamic GHEs).

The properties of the system such as thermal transfer fluid concentration, minimum system operating temperatures, etc. shall be taken into consideration when determining the Reynolds number.

The thermal loops and header pipes shall be designed to ensure that pumping power requirements are kept to a minimum when included with the indoor pipe work and heat pump head loss. The maximum system pump power requirements should in most cases be less than 2.5% of the heat pump thermal output capacity at the lowest operating temperature, with every endeavour made to minimise the pumping power. For example, a 100 kW heat pump capacity should have a maximum pump power requirement of less than 2.5 kW.

Pipework shall be dimensioned so as to ensure that flushing and purging requirements can be met and large loop fields shall be arranged in multiple headers to ensure that the system can be flushed efficiently and in accordance with Section 10.4.

7.7 Transition Fittings

Transition fittings shall be used to adapt to copper or threaded pipe work above ground or in easily accessible locations only. Acceptable transition fittings include flange; threaded; victaulic; barbed and clamped. Pipes and fittings should be anchored if necessary to account for possible contraction and expansion of pipes.

7.8 Leak Free Installation

The system shall be installed as a leak-free installation and for the design life of the installation, which should generally be a minimum of 50 years.

8.0 THERMAL PILE CONCRETE

8.1 General

Concrete thermal conductivity is an important aspect of thermal pile design as it will influence the transfer of heat within the pile. Where possible the designer should ensure high conductivity materials are used in the concrete mix design. However, it is recognised that the final mix design will be a balance of the structural, constructability and thermal needs of the pile. The viability of importing aggregate over long distances should also be considered.

8.2 Concrete Thermal Conductivity

Concrete thermal conductivity depends mainly on the aggregate lithology, aggregate volume ratio and concrete water/cement ratio. In order to maximise the thermal conductivity high aggregates volumes with high quartz content should be used. Generally the use of admixtures and cement replacement products may reduce the thermal conductivity. Initial research suggests that use of PFA may enhance the thermal properties.

In the absence of specific information regarding the aggregate type and proportions then experience suggests that thermal conductivity of pile concrete should not be assumed to be greater than 1.5 W/mK. Where it is known that a high volume of siliceous aggregate has been used in the concrete mix then higher values may be adopted (refer to Appendix G). If the design of the thermal pile scheme is shown to be sensitive to the concrete thermal conductivity then consideration should be given to testing of the design mix.

Concrete thermal conductivity can be determined by the following tests:

- BS EN ISO 12664:2001 Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of medium and low thermal resistance.
- BS EN ISO 12667:2001 Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of high and medium thermal resistance.
- ASTM C177 Test method for steady state heat flux measurement and thermal transmission properties by means of the hot guarded plate apparatus.
- ASTM C518 Test method for steady state heat flux measurement and thermal transmission properties by means of heat flow meter apparatus.
- ASTM C1363 Standard test method for thermal performance of building materials and envelope assemblies by means of a hot box apparatus.

As these test methods involve samples in an oven dry condition and pile concrete is likely to be saturated once installed in the ground, correction of the test results will be required. Suggested methods are given in the American Concrete Institute Report 122R-02, “Guide to Thermal Properties of Concrete and Masonry Systems” and CIBSE “Guide A, Environmental design, Chapter 3: Thermal properties of building structures”.

9.0 LOOP INSTALLATION, PROTECTION, TRIMMING & HEADERING

The chain of responsibility in the following sections can sometime be unclear particularly when a piling contractor has been involved in the construction of thermal piles, with the headering process done by others. Responsibilities should be agreed during the contract setup (refer to Section 3.0).

9.1 Pipe and Loop Delivery to Site and Storage

All pipes shall be delivered suitably wrapped from the manufacturer and fitted with protective caps to prevent debris from entering the pipe work on site. The caps shall only be removed when the pipe is to be connected to the system.

Pipes shall be brought to site and unloaded and stored using correct handling equipment. Pipes shall not be pinched, dropped, dragged or mishandled on site and accidental damage during delivery and handling shall be avoided.

Pipes shall be stored in dry areas of the site that are not subject to build up of rain water in puddles or creation of muddy surfaces. The pipe work shall be stored in a manner so as not to damage the ends of the pipe or the main body of the pipe. They shall be stored in areas that are not prone to other heavy site traffic etc. that may cause accidental damage to the pipes. Thermal loops shall be stored on pallets to ensure they are not directly in contact with the ground and the possible sharp stones that may exist at the surface. Straight pipes shall be supported sufficiently based on their diameter to ensure that no part of the pipe comes into contact with the ground where sharp stones or objects may be lying. The number of supports will depend on the diameter and SDR of the pipe in question.

Pipes should also be stored in a manner that prevents contamination with substances at the surface; e.g. oils etc, which could cause environmental risks to groundwater and the integrity of the piping product.

9.2 Thermal Loop Installation

The piling contractor should undertake a visual inspection of each loop prior to use, and check the issue tag and certificate is appropriate for the pile under construction.

The thermal loop pipework shall be fixed onto the reinforcing cage or central bar in locations as specified by the GSHP Designer. Plastic cable ties, fixing loops to the cage, should be positioned at regular intervals to ensure loops are secured tightly to the cage and remain so during assembly, relocation and the pouring of concrete. The optimum fixing position of the loops is on helical reinforcement between and not adjacent to main bars. Wire ties should be avoided due to potential point load damage that may occur to the loops.

Where loops are required to extend below the base of the reinforcing cage, cage formers or rings, at suitable intervals, should be used to separate the loops and to position the loops as close to the perimeter of the pile both to obtain good heat transfer into the surrounding soils and also to avoid direct discharge of vertical cascading concrete. Where loops hang below the length of the reinforcement cage, weights should be used to ensure the loops remain vertical and in position.

Where concrete is placed by a tremie technique (involving upward flow of concrete), additional support must be given to the loops (i.e. reinforcing cage) to prevent any potential kinking of the loops. Distortion of the U-tube may occur at the base of the pile and upward flow of concrete could cause kinking to the loop, therefore the U-bend needs to be restrained by further fixings.

The loop shall be filled with clean potable water prior to or during installation in order to undertake a flush test. This is used to determine and confirm the loops are satisfactory for use. Any loop failures should be fully removed and immediately replaced or repaired to the satisfaction of the GSHP Contractor. Biocide shall be used to the manufacturer's recommendations when there is any question

over the cleanliness of the water or the loop is to be left full for longer than 21 days after pile completion, and prior to filling with thermal transfer fluid.

As the loop, now fixed to the reinforcement, is lowered into the pile, a visual inspection of the loop pipe shall be made for surface damage. A maximum tolerance of 10%¹ of the wall thickness for scratches on the surface shall be acceptable for installation. Damaged sections of pipe shall be cut out and jointed according to the pipe jointing details described in Section 7.0.

During concreting of the piles, the thermal loops should be filled with water and subject to nominal pressure in order to prevent the pipe from being crushed by the fluid concrete.

On completion of the concreting, and as soon as practically possible, the pile should be subjected to a reversible flow test and pressure test. This test is undertaken to confirm the suitability of the loops and the integrity of the installation. This test should be witnessed by a representative of the Client or Main Contractor, and be recorded with the results forwarded to the same. This test may also be used as a handover to transfer responsibility to the next contracting party (refer also to Section 0).

The optimum position of the loops is on the inside of a reinforcing cage. Where this is not practical i.e. spliced reinforcement cages, loops may be positioned on the outside of the cage providing that adequate cage centralisers / spacers are utilised. The original cover specified for the reinforcement can still be achieved with the loop installed within the cover zone. See Appendix H for further details of this matter.

9.3 Protection Measures for Thermal Loops

The thermal loop shall be installed via a loop installation reeler, either powered, manual or similar, in order to avoid the possibility of damage and contamination to the loop pipe on the site prior to its installation. The uppermost edge of the pile bore or surface casings shall be covered with a smooth edging to prevent chaffing or damage to the loop pipe during installation.

The Piling Contractor has a responsibility to ensure the loops are installed into the pile without damage, kinking and excessive abrasion. The piling technique, and in particular the interaction of the method of concreting and the pipework, is critical. In the event that methods to prevent abrasion or scratching greater than 10% of the wall thickness cannot be used, then additional protection to the potentially affected loop section must be provided.

- Where loops are inserted into fresh concrete, excessive surging of loops on a central reinforcing bar as a means of facilitating insertion (i.e. continuous flight auger piles), is not recommended. The concrete mix specification should be adjusted in line with the concrete supplier's recommendations.
- Where concrete is added after placing the loops, this will normally be via a tremie pipe. Loops should not be placed under the direct discharge of the end of the tremie pipe but be placed close to the pile circumference using helical rings or cage formers. All loops are to be kept vertical (except for U bends) to lessen potential concrete impact. Fusion welded U bends may give better protection from abrasion than natural pipe bends, as these are manufactured using thicker plastic. Alternatively, consideration may be given to using PE-Xa pipe which offers more resistance to scratching.
- Where there is an identifiable risk of abrasion to the loop from the concrete that cannot be avoided, then those areas of exposed loop, additional protection should be considered along with extending the tremie pipe length. Trials may be necessary to demonstrate the adequacy of the scratch protection.

¹ Water Industry: Information & Guidance Note (March 2003) The choice of pressure ratings for polyethylene pipe systems for water supply and sewerage duties, IGN 4-32-18.

Any loop weights shall not have sharp or raised edges, which may be placed in close contact with the loop pipe and cause damage during the design lifetime of the loop.

Once loops are installed in the pile, the caps shall be securely fitted again and the pile bore covered or protected in order to maintain the integrity of the loop until such time as the loop has been flow and pressure tested. On completion of the flow and pressure test, caps shall be fused onto the loops to provide protection from material entering the loops prior to connection to the header system.

The following minimal measures should be put in place to protect the loops in the pile heads, to prevent potential damage during and after piling operations, particularly from the concrete trimming operation.

- In the pile trim zone, each loop end must be appropriately protected according to the method of pile trimming to prevent impact damage from the pile trimming tools. The protection should extend 100mm below the specified concrete cut off level.
- Above the pile trim zone, further protection should be considered. This is dependent on the risk of further damage from backfilling, associated operations and site traffic.

9.4 Pile Trimming

Piles heads should be trimmed with care and in accordance with the industry standard procedures. The trimming contractor must be appraised to the presence of the loops within the top of the pile and use all means at his disposal to safeguard the integrity of the loops. Any cuts or breaks to the loops must be sealed off immediately by recapping to prevent any ingress of debris.

Once pile trimming work commences the GSHP Contractor should be on site supervising pressure tests of exposed loops before his acceptance in to scheme.

Once pressure testing has demonstrated compliance to the satisfaction of the GSHP Designer, any backfill of trenches containing loops from the top of piles to the plant room should be undertaken with an appropriate backfill material as recommended by the GSHP Designer and pipe manufacturer.

9.5 Header Pipe Installation

Portions of the ground heat exchanger (thermal piles connected in series) shall be capable of being valved off and isolated at a manifold, in the event of an individual pile loop failure.

Where horizontal header pipes are laid into a trench and bends are formed, the minimum bend radii shall be as determined by the pipe manufacturer (see Section 7.1). Care must be taken to ensure that pipes do not 'kink' around corners and, where required, elbow fittings will be used to prevent kinking.

Prior to backfilling, the trench bottom shall be inspected to ensure that no sharp objects are present.

Backfill material shall be inspected prior to re-installation to ensure the suitability of the backfill and ensure that no sharp objects or rocks exist in the backfill. Samples of the backfill materials shall be to the approved by the GSHP Designer.

Where excavated material is not suitable for backfilling, sand shall be placed in the trench bottom, around and above the pipe work. The Water Industry Specification for Bedding and Sidefill Materials for Buried Pipelines (WIS 4-08-02)², which outlines suitable backfill procedures, shall be consulted if any doubt exists.

Pipework shall not be laid over hard objects, such as a concrete edge, without additional support or protection.

² Water Industry Standards (1994) Specification for Bedding and Sidefill Materials for Buried Pipelines.

Any ground heat exchanger pipe passing within 1.5m of a wall, structure, drainage pipe, private drainage system (septic tank, package treatment plant or cesspit) or water pipe shall be insulated with non-compressive insulation suitable for operation at all temperatures and conditions experienced by the ground heat exchanger system.

Warning tape shall be laid directly above all horizontal header pipes. The warning tape shall clearly identify that they protect "Geothermal Pipes Below". Ideally, this tape should be detectable to prevent pipework being damaged by any future works.

Header pipe minimum depth of placement should generally be 1000mm to avoid other services where possible and in systems without an antifreeze component in the thermal transfer fluid, to avoid frost damage to ground heat exchangers.

Where feed and return pipe work is within the same trench, a minimum of 500mm between feed and return pipe shall be maintained, either vertically or laterally. Where the minimum distance cannot be maintained over long pipe runs, insulation shall be used either over the pipes or with the use of insulation materials between pipes.

Completed sections of header arrangement should be filled with water and pressurised. Pressure gauges should be set up within the completed section and regularly monitored as construction work proceeds to ensure system remains undamaged.

Once thermal loop installation is completed, the system should remain under pressure until connected to heat pumps. The installed system should be regularly monitored as construction work proceeds to ensure system remains undamaged.

Any sudden pressure drop at any stage must be reported immediately to the GSHP Designer and the Engineer.

10.0 FLUSH, PURGE & PRESSURE TEST OF GROUND HEAT EXCHANGER

10.1 Quality Control

A schedule of the flush, purge and pressure test results shall be maintained by the party responsible for carrying out the test. Where possible, the tests should be independently witnessed. Copies of the test results should be collected by the Main Contractor.

Each thermal loop shall be delivered to site with quality control certificates from the manufacturer accompanied with a pressure test certificate. Where completed sub-assemblies, such as valve vaults and manifolds are delivered to site, these shall also be accompanied with a pressure test certificate from the manufacturer.

During installation of the loop, a visual inspection of the pipe shall be made as the loop is inserted into the pile for visible signs of pipe wall damage. A maximum indentation or scratch of 10% of the pipe wall thickness shall be allowable and any indentation or scratch in excess of 10% of the pipe wall thickness shall not be installed.

10.2 On-site Pressure Testing

There are several key stages in the process at which hold points should be observed to check that loops have not been damaged by construction activity. It is recommended that the GSHP Contractor in conjunction with the Main Contractor and other key parties establish a testing regime that demonstrates traceability at all levels. The contracting parties should determine which of the hold points listed in Table 10.1 should be incorporated into the site inspection and testing plan (ITP), however if at any time there is a cause for concern that a loop may have been damaged then an appropriate pressure test should be carried out.

It is further recommended that a specialist GSHP Contractor should be on hand to witness and undertake the testing of loops at each key stage. On successful testing at hold point 7, responsibility of thermal loops becomes the GSHP Contractor's.

Hold point	Responsible Party	Recommended Test
1. Assembly of loops (potentially with connections/u-bends)	Loop manufacturer / GSHP Contractor	Type A - pressure test with documentation
2. Arrival of loops on site	GSHP Contractor / Piling contractor	Observation - no kinking or damage to pipe
3. During installation within cage	Piling Contractor	Observation - no kinking or damage to pipe
4. Preconcreting of pile	Piling contractor	Bi-directional flow test and Type B - pressure test
5. Immediately post concreting of pile	Piling contractor	Type C - pressure test
6. Pre-trimming of pile heads	Piling contractor / Groundworks Contractor	Bi-directional flow test and Type B pressure test
7. After trimming of pile heads pre connection into header arrangement	Groundworks Contractor / GSHP Contractor	Dip test/Bi-directional flow test and Type C pressure test /
8. Connection of thermal pile loops into zones	GSHP Contractor	Modified test / Type 2 test ref. WRc.
9. Connection of zones to plant room manifold	GSHP Contractor	Final handover test

Table 10.1: Recommended testing hold points

As a minimum, all joints shall remain accessible until such time as a pressure test has been completed. During flushing or test periods, visual inspections of all joints shall be made. Where inclement wet weather may make it difficult to identify small leaks, the joints shall be wiped with a cloth to clear the rainwater and the visual inspection then made. Where weather conditions make it impossible to visually inspect the joints, on completion of the test, the system shall be left under pressure for a minimum of 24 hours.

Any test failures should be reported to the GSHP Designer and the Engineer such that suitable remedial action to replace any damaged loop can be approved and carried out in a timely manner.

10.3 Tests During Pile Construction and Trimming - Table 10.1 (Hold points 1-7)

10.3.1 Observation Test

This involves a visual inspection of the thermal loop pipework to ensure that it is installed as described in Section 9.0.

10.3.2 Type A - Water Pressure Test

This test is normally undertaken off site with the loop pressurised to 150% of the pipes working pressure (refer to Section 7.5) once the thermal loops have been assembled and before delivery to site. In factory conditions, an air pressure test may also be appropriate. If the thermal loops are assembled on site, this test may also be carried out on site after assembly. The acceptance criteria allows no loss of pressure during the test to ensure the loop is leak free.

10.3.3 Bi-directional Flow Test

For this test the thermal loop is filled with water and a check is carried out to ensure that there is flow in both directions of the loop. The acceptance criteria allows no visual loss of flow throughout the test.

10.3.4 Type B - Water Pressure Test

This test is carried out on a water filled thermal loop pressurised to 8 bar. This pressure is maintained at 8 bar for 10 minutes by adding water as necessary (plastic pipe will creep over time, and the pressure therefore relaxes if water is not added). The pressure is then reduced to 4 bar and held for 30 minutes. The acceptance criteria allows no loss of pressure over 30 mins.

When this test is carried out before the piles are concreted, a nominal water pressure should then be maintained within the loop during concreting by capping each end. Where necessary, the pressure may also be monitored whilst concrete is being poured. The pressure is expected to rise during concreting, preventing the pipe from being crushed by the fluid concrete. Provided no sudden pressure losses are observed during concreting then the concreting process can be deemed to have been carried out successfully.

10.3.5 Type C - Water Pressure Test

This test is carried out on a water filled thermal loop pressurised to 8 bar. The pressure is maintained at 8 bar for 10 minutes by adding water as necessary (plastic pipe will creep over time, and the pressure therefore relaxes if water is not added). The pressure is then reduced to 4 bar and held for 24 hours. The acceptance criteria for the test allows no loss of pressure after 24 hours (when carried out immediately after concreting, the pressure should rise during the test).

10.3.6 Dip Test

This test uses a probe e.g. weighted tape, to confirm that the depth of the installed thermal loop is as specified. The risk of possibly getting a probe stuck within the loop should be considered.

10.4 Purging the System

On completion of the ground heat exchanger or at stages throughout the installation of larger ground heat exchangers the system shall be flushed in order to remove debris and air. The flushing equipment shall be capable of delivering a sufficient flow rate and head pressure to achieve a minimum of 0.61 m/s velocity in any pipe diameter in the system. If there is a likelihood of build up of silt, grit etc. in the pipework, or connections are made to steel pipework within the closed loop, then reference should be made to the pipework flushing recommendations in BSRIA document BG29/2011¹.

The flushing pump system shall be capable of reversing the flow without removal of hoses, monitoring the delivery and return pressure, monitoring the flow rate being delivered, have means of inspecting the fluid with a sight glass and shall be capable of filtering debris from the system. All values shall be recorded for the system Operations & Maintenance (O & M) Manual.

Visual inspections of the return flow through a sight glass shall be carried out and once the return is free from visible air bubbles the flushing at the minimum of 0.61 m/sec shall be maintained for a minimum of 15 minutes, or longer for larger ground heat exchangers.

10.5 Final Stage Tests - Table 10.1 (Hold points 8 & 9)

10.5.1 Modified Test / Type 2 Test

The test procedure shall be in accordance with BS EN 805 section 11.3.3.4 which allows a modified test to be carried out for polyethylene pipes. The modified test shall be in accordance with WRc "A Guide to the Testing of Water Supply Pipelines and Sewer Rising Mains" 1st Edition, June 1999, Section 5 (available from <http://www.wrcplc.co.uk/default.aspx?item=339>) or BS EN 805 Annex 27 (<http://www.bsigroup.com/en/Standards-and-Publications>). The test pressure for the loop shall be determined based upon the density of the pile grout/concrete placed and the depth of the installed loop.

The ground heat exchanger array shall be fully purged of air prior to the test commencing. The ambient temperature shall also be monitored during the test and notes shall be taken as to whether the pipe line is exposed to direct sunlight or other conditions which may affect the results of the test.

The tests involve pre-loading periods and main test periods. The main test should not commence until the pressure reading has settled after pre-loading. The fluid volume added to the test section shall be monitored accurately and the pressures and time shall be accurately monitored. The testing equipment shall be capable of an automated addition of water to ensure accuracy and exact duplication of each test. The test pressures shall be attained as uniformly as possible, by a steady linear increase in pressure. The corrected results of the WRc test shall then be plotted on a logarithmic scale and assessed for a pass or a fail as per Figure 10.1 below, where a straight line indicates a pass and anything other than a straight line indicates the test has failed.

¹ BSRIA (2011) Pre-commission cleaning of pipework systems, BG29/2011.

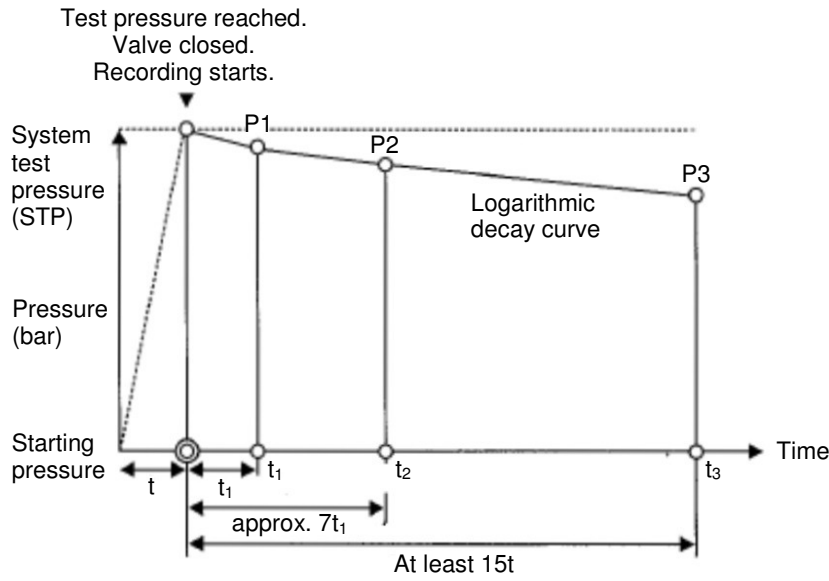


Figure 10.1: Graph of pressure versus time for pressure test pass/fail assessment

A test failure however does not automatically assume the array is leaking as the test could also fail due to excess air in the system that has not been purged correctly, as outlined in Section 10.4. The volume of water added to the loop shall be plotted against pressure to identify whether there is still excess air in the loop during the test as outlined in Figure 10.2.

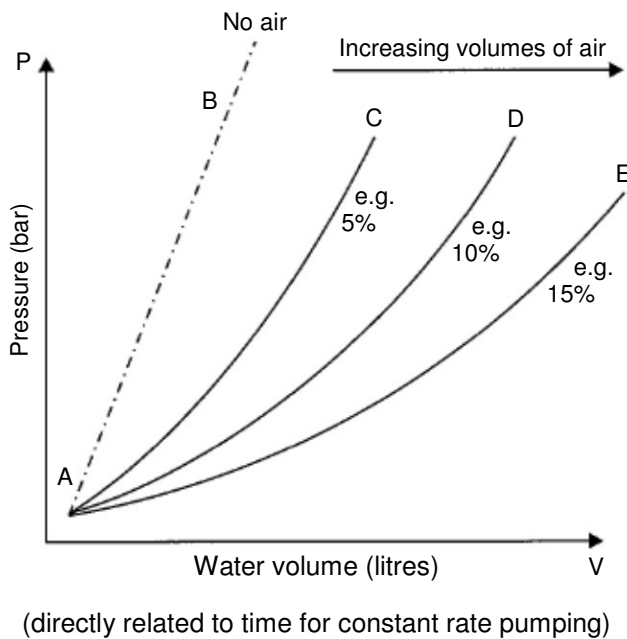


Figure 10.2: Graph of pressure versus water volume to establish presence of excess air

The BS EN 805 Annex A.27 test would be plotted on a graph as outlined in Figure 10.3.

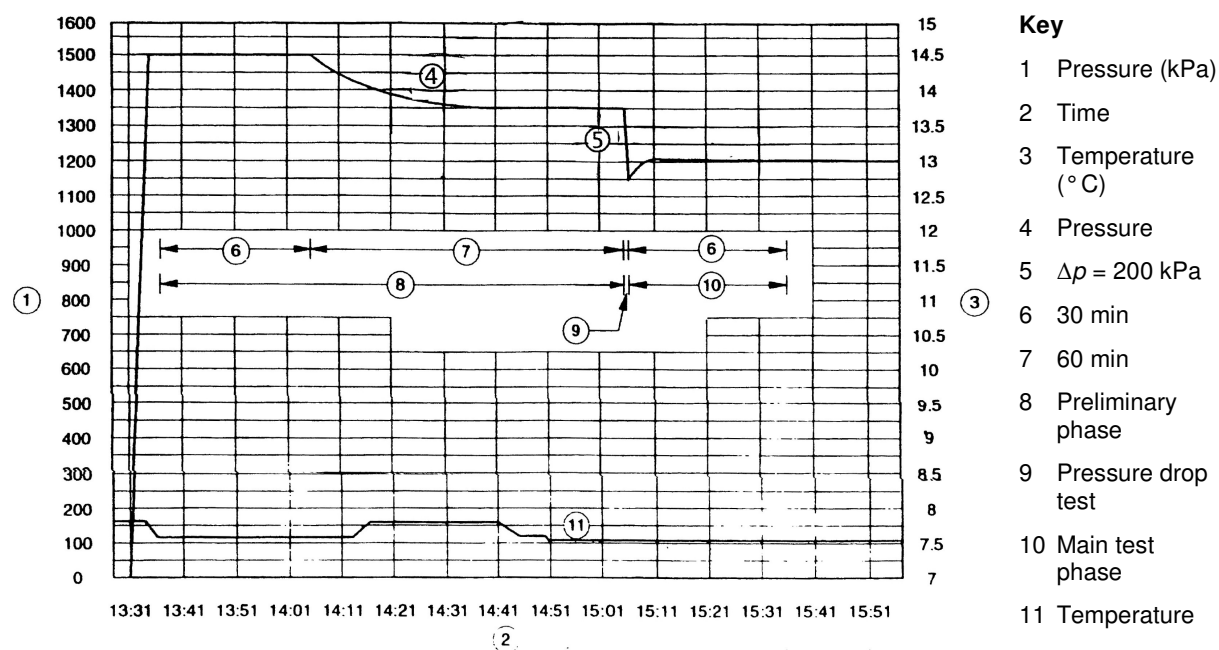


Figure 10.3: Graph of pressure versus time as plotted in BS EN 805 Annex A.27

As different loop lengths may exhibit different pressure test characteristics, the first loop test shall be extended in order to ensure categorically that the loop does not leak and therefore to arrive at control values for pressure at the normal testing periods, for the remainder of the loops to be tested. On reaching the end of the normal test, the loop shall be left under pressure for a minimum of a further 12 hours with periodical measurement of pressure and plotting against the log scale.

Simplification of the above test procedure can be accomplished by the use of third party data logging equipment. Devices with inbuilt data processing facilities can facilitate early leak detection and clearer understanding of the pressure decay during the test, assisting in identifying the cause of any leakage within a test section.

10.5.2 Final Handover Test

The GSHP system shall be flow tested either in its entirety or in sections depending on the size of the ground heat exchanger. The pressure drop for the system section being tested shall be compared to design calculated values. A minimum of 3 flow rate and head loss measurements shall be taken at flow rates in excess of the system design flow rate for the section under test. The measured values shall be compared to design calculated values at the same flow rates to ensure that there is no blockage or kinking of any pipe.

Head loss measurements shall be determined by using a pressure measuring device directly on the flow and return leg of the system being flushed. The differential pressure between the two values shall represent the test section head loss.

11.0 INDOOR PIPING & VALVE VAULTS

11.1 Circulator Sizing and System Components

The circulating pump shall be selected such that it will be capable of delivering the heat pump manufacturer or GSHP Designer's minimum flow rate under all operating conditions (refer to Section 7.6).

Where heat pumps are installed with integral circulating pumps the ground heat exchanger shall be designed in order to be fully compatible with the flow rate and developed head of the integral circulating pump.

The thermal transfer fluid properties and minimum operational temperatures shall be considered when sizing the circulating pump.

Debris and air shall have been removed by flushing prior to starting the circulating system.

Prior to start up, the loop shall be pressurised in accordance with manufacturer's recommendations:

- For example to 1.4 – 2.0 bar in summer cooling periods with circulating water between 20°C – 30°C, and;
- 2.75 – 3.5 bar in winter heating conditions where the water is circulated at 5°C or lower.

Where pressurisation units are installed, the sizing of such units shall take into consideration the fluid thermal properties, the pipe component thermal properties, maximum and minimum pressure requirements for the pump and system. Any make-up fluid for automated topping up of the system shall be stored in containers sealed against contamination and contain a biocide to ensure no system contamination occurs during dosing. Where mains connected auto-fill units are installed, the operation of such units shall be linked to the BMS as a "fault alarm" and be fitted with a double check valve, and comply with all local water authority requirements.

Circulating pumps that include volute design and which meet manufacturers' requirements are excluded from the requirements of pressurisation.

The circulation system shall have, within 500mm of the heat pump system, the ability to test flow and pressure in order to test the performance of the ground source side of the heat pump. The capability may be integral to the heat pump and directly linked to the heat pump management system or easily accessible manual binder points.

11.2 Valve Vault & Indoor Piping Requirements

Loop flushing and charging valves shall be sufficiently plugged and/or be equipped with removable handles to ensure that no accidental leakage of loop fluid can occur.

Boiler-type service valves shall not be used.

Transition fittings between differing materials shall be easily accessible.

All indoor piping where condensation may form shall be insulated according to the current Building Regulations and the relevant standards (BS 5422¹, BS 5970², etc.).

¹ BS 5422:2009 Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C, BSI.

² BS 5970:2001 Code of practice for thermal insulation of pipework and equipment in the temperature range -100°C to +870°C, BSI.

Any above ground exterior piping shall be fully insulated with exterior grade non-compressive insulation with suitable UV resistance.

Where pipes pass through walls or structures, they shall be sleeved and the annulus between the pipe and sleeve fully sealed with non-hardening sealing compound or components and/or insulation as required.

Where pipes are within 450mm of the surface, or 700mm from mains water supply, and the system is antifreeze free, they shall be insulated with materials suitable for underground application and shall be non-compressive.

Where threaded connections are used, good quality clean threads shall be used with specific sealants taking into consideration the antifreeze being used, if any.

Valve chambers and vaults shall be designed so as to provide the minimum additional head loss in the systems. In particular, valves shall be full flow valves and all pipework to and from the valve manifolds shall be designed for the flow rates experienced in each part of the manifold.

Pressure and temperature ports shall be installed on flow and return to the manifolds.

Underground chambers requiring personnel access shall be designed to minimise risk to personnel, including a means of ventilating the chamber prior to personnel entry and ensuring that all safety notices and warnings are clearly displayed. The valve vaults shall be fully sealed and free from any leaks of groundwater into the chamber. The structural stability of the chamber shall be considered when deciding the type of housing.

12.0 THERMAL TRANSFER FLUID REQUIREMENTS

12.1 Thermal Transfer Fluid Selection, Use & COSHH Requirements

Thermal transfer fluid refers to the secondary fluid permanently installed in the thermal loops within the ground heat exchanger. The fluid will include components of antifreeze, biocide and corrosion and scale inhibitors.

The thermal transfer fluid material shall be compatible with all components within the GHE including all pipework, valves, pumps, heat exchangers, expansion vessels and heat pumps. If in doubt, the installer/designer shall provide details of the fluid to be used to all component manufacturers whose products are intended for use in the system for verification of compatibility with their products. Compatibility data for system materials shall be made available on request.

The GSHP Designer, supplier and installer shall all be aware of the Control of Substances Hazardous to Health (COSHH) regulations¹ and shall comply with these regulations where applicable. The designer and installer shall make their own selection of fluid and shall ensure that operatives are fully aware of all safety requirements for the use of the fluid and be familiar with the product. Reference shall be made to the product's Safety Data Sheet for information on its origin, composition, stability, hazard ratings, toxicity, handling & storage, regulatory information and fire/release/exposure response.

The thermal transfer fluid shall be biodegradable, non-toxic to the environment, not have acute oral toxicity and be non-flammable. Preferably, it should also be non-hazardous (i.e. bear no standard hazard symbols or pictograms on its container or in the appropriate section of its safety data sheet).

JAGDAG (Joint Agencies Groundwater Directive Advisory Group)² has published information relating to the protection of groundwater from hazardous substances and the appropriate environmental agencies with responsibility for its regulation.

Under the Water Framework Directive and the Groundwater Daughter Directive, EU Member States are required to protect groundwater against pollution and deterioration by preventing or limiting entry of pollutants to groundwater. In the UK the appropriate regulatory bodies with responsibility for the identification of hazardous substances are the Environment Agency (England and Wales), the Scottish Environment Protection Agency and the Northern Ireland Environment Agency. Collectively these agencies' decisions are reviewed by JAGDAG, who represent the three aforementioned agencies as well as the Department of Environment, Food and Rural Affairs (DEFRA), the Welsh Assembly Government (WAG), the Environmental Protection Agency Ireland (EPA), the Health Protection Agency (HPA) and industry representatives.

The old Groundwater Directive (80/68/EEC)³ aimed to protect groundwater from pollution by controlling discharges and disposals of certain dangerous substances (defined under Lists 1 and 2) to groundwater. This Groundwater Directive is to be repealed by the Water Framework Directive 2000/60/EC⁴ (WFD) in December 2013. The WFD and new Groundwater Directive (2006/118/EC)⁵ - commonly referred to as the Groundwater Daughter Directive (GWDD) supersede Directive 80/68/EEC and make some changes to the way pollutants are assessed. Member States now only need to define which substances are hazardous, all other pollutants being non-hazardous. Both hazardous substances and non-hazardous pollutants are subject to control.

¹ <http://www.hse.gov.uk/coshh/>

² <http://www.wfduk.org/jagdag/>

³ Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances.

⁴ Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

⁵ Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration.

The UK administrations have now transposed the GWDD into domestic legislation as follows:

- England & Wales - the Environmental Permitting Regulations 2010⁶
- Scotland - The Water Environment (Groundwater and Priority Substances) (Scotland) Regulations 2009⁷
- Northern Ireland - The Groundwater Regulations (Northern Ireland) 2009⁸

Under the GWDD the UK is required to publish a list of substances that it considers to be hazardous on the basis of their intrinsic properties. Hazardous substances effectively replace the previous List 1 substances and are defined in the WFD as:

“Substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances which give rise to an equivalent level of concern”

12.2 Specific Thermal Transfer Fluid Requirements

The thermal transfer fluid shall be classified as inherently and ultimately biodegradable as measured under OECD Guideline No. 302B (1992) “Inherent Biodegradability: Modified Zahn-Wellens/EMPA Test” EEC Commission Directive 87/302/EEC and US EPA Fate, Transport and Transformation Test Guidelines OPPTS 835.3200.

The fluid shall not be harmful by ingestion (as originally classified by the EEC Dangerous Products Directive 1999/45/EC) and shall not have an acute oral toxicity of more than 2000 mg/kg as assessed under OECD Guidelines OECD 401, OECD 420 or OECD 423. The Thermal Transfer Fluid shall be classified as Category 5 for Acute Toxicity under the Globally Harmonised Classification System (GHS).

The fluid shall not be harmful to the environment as classified under EEC Dangerous Products Directive 1999/45/EC and or CLP legislation 1272/2008 (must not bear Risk Phrases R50 to R59 inclusive).

The fluid shall have suitable and appropriate levels of corrosion and scale inhibitors where required and shall be compatible with all materials and components within the ground source system.

The thermal transfer fluid shall be non-flammable as determined by ISO 2719 for flash point and ISO 9038 for combustion.

Freezing point of the fluid as measured according to ASTM D1177 and setting point as measured according to DIN 51583 (DIN EN 23015) shall be sufficient to fully protect all components including the heat pump evaporator under static conditions following heating, taking into account the required freeze protection below the minimum fluid temperature.

The minimum concentration requirements of the fluid shall be strictly in accordance with the manufacturer’s recommendations.

Great care will be exercised to ensure that the freeze protection provided by the antifreeze component of the thermal transfer fluid shall be exactly as specified by the GSHP Designer.

The make-up water used for the mixing of the thermal transfer fluid shall be, as a minimum, potable mains water supply quality.

Upon arrival to site, the fluid shall be homogenous without settlement, uniform in colour, and have no lumps, skin or foreign matter.

⁶ The Environmental Permitting (England and Wales) Regulations 2010.

⁷ The Water Environment (Groundwater and Priority Substances) (Scotland) Regulations 2009.

⁸ Groundwater Regulations (Northern Ireland) 2009.

The fluid shall be supplied to the job site in suitable manufacturer's containers with manufacturer supplier suitable labelling identifying the material, toxicity signage, concentration and emergency telephone numbers. Transport documentation and labels shall comply with current transport regulations.

If requested, the manufacturer shall provide an up to date Safety Data Sheet (compiled in accordance with European Regulation 1907/2006 (REACH) as amended by Regulation 453/2010) with each shipment.

12.3 Inhibitors & Biocides

Where the thermal transfer fluid has corrosion inhibitors and/or biocides, the thermal transfer fluid shall conform to the above safety, non-flammability, degradability and toxicity requirements. The addition of such chemicals shall not lower the levels outlined in section 13.2 above which may then allow the thermal transfer fluid to fall outside of the required standards.

12.4 Safety Notices for Thermal Transfer Fluids

At all access points to the fluid such as flushing valves, there shall be a notice detailing the fluid installed and any emergency procedures in accordance with the fluid manufacturers requirements. The notice shall also detail the concentration of the fluids where appropriate.

12.5 Filling of Thermal Loops with Thermal Transfer Fluid

The method for filling the system must ensure that the entire GSHP system contains thermal transfer fluid to the correct concentration. These concentrations shall be obtained from the manufacturers and strictly complied with. It is important that sufficient external mixing has been carried out to ensure a homogenous fluid. The use of antifreeze based thermal transfer fluid enables the circulating thermal loop fluid temperature to fall below 0°C, which prevents damage being caused to plant through the freezing of the fluid. Without precautionary measures, the use of thermal transfer fluid could also result in low temperatures, which are beyond the structural design specification of the thermal piles. Consideration must therefore be given to the lowest design temperature and how this is controlled. Refer also to Section 5.7.3.

13.0 DESIGN DRAWINGS & AS BUILT RECORDS

13.1 Design Drawings

The GSHP Designer shall produce detailed, dimensioned design drawings of the proposed location of the thermal piles and the header pipes within the foundation of the building in a suitable electronic format based on the space available for the installation and in accordance with BS EN ISO 7519¹. Where concept sketches are required as pre-design, sketches shall be clear, to scale and drawn with due skill and care to be representative of the installation.

The design drawings shall be discussed with the client to ensure that the design drawings can be upgraded to installation drawings, taking into consideration the client's drainage, water and gas supplies and other utilities or underground hazards.

When installation is complete, the drawings shall be upgraded further to 'as built' drawings, taking into account any unforeseen alterations required during the installation.

The Main Contractor and Client shall be provided with copies for future reference or as required under the contract.

13.2 Installation Records

The design drawings, design information, pressure test certificates, flow testing, antifreeze concentrations and flushing results shall be provided to the Client. The GSHP Contractor shall also keep a copy for their records. Operation and Maintenance manuals will also be issued to the Client.

13.3 Re-instatement

Prior to commencement of the works, the contractors and any of their sub-contractors shall agree in writing the level of re-instatement required for the works and clear lines of responsibility of part re-instatement required prior to landscaping works carried out by others.

The written agreement shall incorporate clear definition of the backfill materials, level of compaction of trenches and surface finish.

¹ British Standards Institution (1997) Technical drawings. Construction drawings. General principles of presentation for general arrangement and assembly drawings.

14.0 MONITORING AND CHECKING PERFORMANCE

The primary function of piled foundations is one of providing essential structural support, and it is of paramount importance that the primary function of these foundations is not comprised in anyway, either in the short or long term. Thus it is recommended that a failsafe method to control and monitor thermal loop temperatures is put in place to enable a comparison of the operational performance of the system against the original design conditions to be made and monitored throughout the life of the building, thereby preventing the GSHP system from exceeding design conditions. The following provides guidelines on how this could be achieved and the key parties that should be involved in the process.

In order to accurately assess the correct amount of thermal loop required, it is essential that a minimum of a monthly heating and cooling profile, together with peak loads should be provided to the GSHP Designer. This information should be developed and undertaken by the M&E Designer (refer to Section 5.5). Where the annual load data is calculated for a time period resolution shorter than monthly, then consideration shall be taken for the inherent weaknesses in using a short time period resolution.

The thermal loop design should be undertaken by a suitably experienced GSHP Designer. Early assessments and calculations should be carried out by the GSHP Designer which then form the basis of planning the long term monitoring, including:

- As built ground conditions, foundation spacing and size
- Flow and return temperatures, ensuring they are within the pile design temperature envelope, as well as avoiding ground freezing or overheating
- Amount of heat removed from or injected into the ground in order to compare with the original M&E design
- Demonstrating that over a period of 100 years of operation, the undisturbed ground temperature change is both sustainable and as agreed with the Pile Designer, typically in the range of 2 to 5°C range

It is also important to note that any changes that occur during construction need to be assessed, as they can have a significant impact on the final heating and cooling load of the building. Changes may include:

- Repositioning building
- Repositioning / removing / changing size and depth of foundations
- Change in fabric of building as part of value engineering
- Change in building use
- Occupancy levels

During the pre-commissioning stage of the ground source system, the parties that developed and produced the original heating and cooling profiles and the resulting thermal loop requirements, such as the M&E Designer, and the GSHP Designer, along with the Main Contractor, should revisit original assessments, to confirm whether any significant changes have been made during the construction process that are likely to alter the load profile. The outcome of this review should then be used as the benchmark to which the system is then monitored over the lifetime of the project.

It is recommended that both DECC / EU MID (Measuring Instruments Directive) approved electrical meters and heat meters on both the thermal loop and load side, are installed such that the GSHP system can be monitored and controlled as necessary throughout the life of the system and to meet RHI requirements. Controls and monitoring should be designed and put in place to ensure the following:

- To prevent thermal loops temperatures deviating outside the design range

- To enable continuous monitoring of monthly heating and cooling profiles against original design profiles
- To ensure that if temperatures deviate outside the design range the BMS can automatically initiate corrective action and at the same time alert engineers of a problem
- To provide an annual assessment of the heating and cooling profile compared to the original design intent
- To measure COP and SPF of heat pumps
- All of the above data should be stored as a continuous record, with readings typically taken at hourly intervals

The performance of the GSHP system should be monitored to ensure that the inflow temperatures to the pile do not fall outside the design limits, refer also to Section 3.14, Section 5.7.3 and Appendix A. Should the GSHP system be operating outside of the appropriate temperature range, the GSHP Designer may be required to investigate if the system is functioning as designed.

To ensure appropriate monitoring is carried out it may be necessary to include information within the building operations manual to this effect. This may need to be specified by the system designers early on in the process.

15.0 SUBMITTALS & ALTERATIONS TO STANDARDS

15.1 Requirement for a Change Process

From time to time, new products, testing requirements, health and safety legislation and environmental requirements may render items within the installation standards obsolete or in need of up-dating.

Under such circumstances the following procedure shall be followed.

15.2 Persons or Organisations Permitted to Submit Change information

Change information to the standards may be submitted by GSHPA members and non-members, including manufacturers, suppliers, installers, designers and specifiers. Change information may also be submitted by regulating bodies, other related trade organisations, Health & Safety Executive and the Environment Agency.

15.3 Standards Change Process

A proposal for the change of a particular standard or section of the standard shall be presented to the GSHPA Secretariat electronically with a copy to the current GSHPA Chair as well as to the current Chair of the GSHPA Training & Standards Sub-Committee (T&SC).

Standards meetings should be held one calendar month prior to a GSHPA council meeting and submissions for review shall be received four months prior to a GSHPA council meeting.

The submission shall clearly identify the section to be reviewed. It shall identify what the proposed revisions are with a single line through wording to be changed and where altered or additional wording is proposed this shall be underlined and in bold font.

The submission shall have a clear, concise reason for each change contained within the submission and the submission shall only enhance the standards to a higher level and shall not reduce the levels of any of the standards.

Where a specific EN/BS standard is referenced, clear details of the standard shall be included with the submission.

The GSHPA reserves the right to amend the above procedure should the need arise.

15.4 Standards Change Review and Outcome

The submissions shall be reviewed by T&SC members individually and comments returned to the GSHPA T&SC Chair with a copy to the GSHPA Chair & Secretariat one week prior to the T&SC standards meeting.

T&SC shall meet with a quorum of minimum 50% of the sub-committee and shall make a recommendation to GSHPA Council Meeting. The T&SC meeting may from time to time be conducted by conference call.

Recommendations shall be one of the following:

- Approve the change submission and amend standards as required
- Approval of a revised change submission
- Disapproved
- Recommend further study and submission from proposer

15.5 Dispute of Outcome

Where a submission outcome is disputed, the person, organisation or body making the submission may make representations to the GSHPA Council.

The submission shall include all relevant information as to why the outcome is disputed. The information shall be provided one month prior to the following GSHPA Council Meeting for review. Failure to adhere to this requirement shall render the dispute resolved in favour of the GSHPA.

The proposer of the change can re-submit their proposal and the same procedure will apply as above.

A bona-fide dispute shall be discussed by the GSHPA Council and shall be decided upon by a vote of all council members and secretariat present at the meeting with GSHPA Chair having a casting vote if needed.

15.6 Records of Changes

The Secretariat shall maintain a record of all submissions, meeting dates, meeting attendees, meeting minutes, recommendations by individual T&SC members, GSHPA Council recommendations, dispute resolutions and date of standards amendments.

The GSHPA publication "Thermal Pile Standards: Design, Installation & Materials" may not be re-published each and every time there is an agreed amendment.

Amendments shall be published on the GSHPA member's website in the member's area. Addendums to the standards can be purchased by non-members.

The standards document shall be reviewed on a bi-annual basis by T&SC and GSHPA Council and the amount of changes approved shall be assessed as to whether they constitute a material alteration in the inference of the standards document, at which point a further revision of the document shall be published.

The changes shall be highlighted in the revised publication with the date of the change approval in brackets next to the section that has been altered or added.

16.0 LIST OF RECOMMENDED READING MATERIALS

Standards and Guides

Organisation	Document Name	Document Ref. No.
ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers)	Heating, ventilating and air-conditioning application. Chapter 32 - Geothermal Energy	
American Society for Testing and Materials	Test method for steady state heat flux measurement and thermal transmission properties by means of the hot guarded plate apparatus	ASTM C177
	Test method for steady state heat flux measurement and thermal transmission properties by means of heat flow meter apparatus	ASTM C518
	Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus	ASTM C1363
British Standards Institution	Code of Practice for site investigations	BS 5930: 1999 + A2 :2010
	Geotechnical investigation and testing - Identification and classification of rock - Identification and description	BS EN ISO 14689-1:2003
	Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description	BS EN ISO 14688-1:2002
	Heating Systems in Buildings, design of heat pump heating systems	BS EN 15450:2007
	Investigation of potentially contaminated sites. Code of practice	BS10175:2001
	Quality management system. Requirements	BS EN ISO 9001:2008
	Technical drawings. Construction drawings. General principles of presentation for general arrangement and assembly drawings	BS EN ISO 7519:1997
	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Dry and moist products of medium and low thermal resistance	BS EN ISO 12664
	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance	BS EN ISO 12667

Coal Authority	Guidance on managing the risk of hazardous gases when drilling near coal	
DCLG	Domestic Building Services Guide, 2010 edition	
	Non Domestic Building Services Guide, 2010 edition	
Department Energy and Climate Change	Microgeneration Installation Standard 3005: Requirements for contractors undertaking the design, supply, installation, set to work commissioning and handover of microgeneration heat pump systems, Issue 3.1a	
Environment Agency	Environmental good practice guide for ground source heating and cooling schemes: 2011	
	Ground Water Protection: Policy and Practice	GP3 2007
European Parliament	Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances	80/68/EEC
	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy	2000/60/EC
	Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration	2006/118/EC
Ground Source Heat Pump Association	Closed-loop Vertical Borehole: Design, Installation & Materials Standards, Issue 1.0	
Health and Safety Executive	Managing Health and Safety in Construction. Construction (Design and Management) Regulations 2007 Approved Code of Practice	
	Protection of workers and the general public during development of contaminated land	HSG 66 (1991)
	The Control of Substances Hazardous to Health Regulations 2002 (as amended). Approved code of practice and guidance	
Institution of Civil Engineers	The Specification for piling and embedded retaining walls, 2 nd edition	
London District Surveyors Association	Guidance notes for the design of straight shafted bored piles in London Clay, Guidance Note 1	
National House Building Association	Efficient design of piled foundations for low rise housing, design guide	

Northern Ireland Executive	Groundwater Regulations (Northern Ireland) 2009	
The Scottish Government	The Water Environment (Groundwater and Priority Substances) (Scotland) Regulations 2009	
SIA (Swiss Society for Engineers and Architects)	Utilisation de la chaleur du sol par des ouvrages de foundation et de soutènement en beton, Guide pour la conception, la realisation et al maintenance	D 0190
UK Government	The Environmental Permitting (England and Wales) Regulations 2010	
	The Pressure Equipment Regulations 1999	
VDI (The Association of German Engineers)	Thermal use of the underground - Ground source heat pump systems	VDI 4640 Part 2 (2009)
Water Industry Standards	Specification for Bedding and Sidefill Materials for Buried Pipelines	WIS 4-08-02
Water UK	Water Industry: Information & Guidance Note, March 2003. The choice of pressure ratings for polyethylene pipe systems for water supply and sewerage duties	IGN 4-32-18
World Geothermal Congress	Sanner et al, 2005. Thermal response test – current status and worldwide application. Proceedings World Geothermal Congress 2005, 24-29, April 2005, Antalya, Turkey	

Reports

Organisation	Document Name	Document Ref. No.
Arup	DTI Partners in Innovation 2002 Ground Storage of Building Energy Overview Report	PII Ref: O-02-ARUP3, May 2005
Swiss Federal Office of Energy	Recommandations pour la realisation d'installations avec pieux echangeurs	120.104, December 1997
	Mesures et optimisation de l'installation avec pieux energetiques du Dock Midfield de l'aeroport de Zurich	June 2007 rapport final

Appendix A: Guidance Regarding Fluid Temperatures in Energy Foundations

This appendix supports the guidance provided in Section 5.7.3.

A number of publications (e.g. Brandl, 1998¹, 2006²) highlight the need to prevent freezing of the soil or the soil-pile interface during operation of thermal piles or other foundation heat exchangers. However, there are few sources of guidance with respect to control limits for fluid temperature to prevent this occurring. Below, the relevant criteria from three sources of design guidance are summarised. Whilst one provides no guidance about the means to prevent freezing, two suggest the approach of ensuring that the fluid returning from the heat exchangers does not fall below 2°C. Exceptions from this simple and conservative approach should only be given if design calculations can demonstrate that lower fluid temperatures are possible without freezing the ground and that operational control systems are in place to prevent minimum fluid temperatures from being exceeded.

To understand the temperature difference between the fluid and the ground an appreciation of the internal behaviour of the pile is required, and this is often characterised in terms of thermal resistance. The thermal resistance will depend on the size of the pile and the number and arrangement of pipes within the pile cross section. Some guidance in this respect is given in SIA (2005)³. The temperature difference is then the product of the heat flux (per metre length of the pile) and the thermal resistance. In extreme cases the temperature difference can be up to 10°C³, but is more likely to be only a few degrees.

To apply a thermal resistance to the analysis of the temperature difference between the fluid and the pile assumes that the pile is at steady state. This is reasonable for longer timescale temperature variations. However, for short duration thermal pulses, which are most likely to result in lowering of the fluid temperature below 0°C, then the pile concrete will behave in a transient manner and act as a buffer to transfer of the heat to/from the ground. In effect, for such short duration pulses, the short term heat storage capacity of the pile is important. This contributes to the ability of the pile to protect the ground from freezing as long as the peak thermal heating requirements are short lived. It is due to these effects that it has been shown to be acceptable to use fluid temperatures as low as -1°C and still prevent ground freezing (Brandl, 2006).

A.1 SIA D 0190 (2005)³

Under principles of design, the SIA guide takes the approach that the return temperature of the fluid in circulation should not fall below zero with a 2°C safety margin. However it later states that a lower return temperature could be permitted if an appropriate control system is in place to prevent to pile-soil interface freezing. Later in the text the guide is more ambiguous simply stating the minimum fluid temperature must be fixed at 0°C.

Paragraph 2.7

“In all cases, except with special permission from the civil engineer, the temperatures imposed on the geostructures must remain positive, with a margin of 2°C.

Operational returning temperatures of the fluid will be maintained with a 2°C safety margin with absolute reliability. This is for the security of the foundations and hence the security of the structure of the building which they support.

¹ Brandl, H. (1998) Energy piles and diaphragm walls for heat transfer from and into the ground. In: W.F. Van Impe & W. Haegeman (Eds), Proceedings 3rd International Conference on Deep Foundations on Bored and Auger Piles, Ghent. A.A. Balkema, Rotterdam, the Netherlands, pp.37-60.

² Brandl, H. (2006) Energy foundations and other thermo active ground structures, *Geotechnique*, 56 (2), 81 – 122.

³ Anstett, M., Hubbuch, M, Laloui, L., Matthey, B., Morath, M., Pahud, D., Parriaux, A., Rybach, L., Schonbachler, M., Tacher, L. & Wilhelm, J. (2005) Utilisation de la chaleur du sol par des ouvrages de foundation et de soutènement en beton, Guide pour la conception, la realisation et al maintenance, Swiss Society of Engineers and Architects, Documentation D 0190.

A lower return temperature is eventually possible if a control system can guarantee that at all times the pile soil boundary does not fall below 0°C.”

Paragraph 7.2

“Variation of the temperature of the heat transfer fluid must be compatible with the static mechanical design of the foundation.

Minimum temperature fixed at 0°C to prevent freezing of the structure. It should be higher than this unless antifreeze is also used.”

A.2 VDI 4640 Blatt 2 Entwurf (Design) 1998⁴

The VDI document “thermal use of the underground” does not extensively discuss use of piles as heat exchangers. It considers the design to be analogous to that for boreholes, but with the exception that freezing temperature should never be reached.

A.3 NHBC Efficient design of piled foundations for low-rise housing Design guide (2010)⁵

The NHBC guide also outlines the principle of prevention of freezing and recommends that fluid temperatures do not fall below 2°C.

“One particular precautionary principle, however, is that the pile must not be allowed to freeze. If the coolant is circulated at temperatures below freezing point, then it will be necessary to demonstrate that the freezing front does not reach the soil interface. It is recommended that geothermal pile fluid circulation temperatures range from ambient ground temperatures down to no less than 2°C.”

⁴ VDI (2009) Thermal use of the underground - Ground source heat pump systems, VDI 4640 Part 2, The Association of German Engineers (VDI), Dusseldorf, Germany.

⁵ NHBC (2010) Efficient design of piled foundations for low rise housing, design guide, NHBC Foundation.

Appendix B: Thermal Properties of Soils and Weak Rocks

B.1 Introduction

The thermal conductivity and volumetric heat capacity of the ground are key parameters for the design of thermal pile systems. The following sections contain information about typical values and also testing techniques for determining site specific values of thermal properties. The information has been restricted to soils and weak rocks as piled foundations for buildings are unlikely to be required where there is an underlying competent rock unit.

B.2 Thermal Conductivity

Typically the thermal conductivity of soils and rocks varies from around 0.2 W/mK to 5 W/mK in the most extreme cases. The thermal conductivity is controlled by the nature and proportions of the soil and rock constituents with the solid particles being the most conductive, followed by water and then air. Quartz is the most conductive mineral and soils which are rich in quartz and also saturated will have the highest thermal conductivity. MIS3005¹ provides guidance on the likely range of values to be encountered, a summary of which is given in Table B.1. In addition, Downing & Gray, 1986², provide details of testing on selected UK lithologies (Table B.2). However, caution should be exercised when using these numbers as most of the source boreholes used for the testing were deep exploration holes for petroleum or geothermal resources. It would therefore be expected that the samples would be of lower porosity and higher moisture content than would be representative of the range of conditions relevant to shallower thermal pile systems.

Given the uncertainty in using the literature as a source of information for the thermal properties of soils, site specific testing is preferable where possible and economic. In situ thermal response testing is the most suitable means of testing (refer to Section 6.0) but in situ needle probe and laboratory testing may also be carried out.

Soil or Weak Rock	Thermal Conductivity (W/mK)	
	Range of quoted values	Recommended Values
Sand, dry	0.3 – 0.8	0.4
Gravel, dry	0.3 – 0.4	0.4
Peat, soft lignite	0.2 – 0.7	0.4
Clay/silt, dry	0.4 – 1.0	0.5
Clay/silt, water saturated	0.9 – 2.3	1.7
Gravel, water saturated	1.6 – 2.0	1.8
Claystone, siltstone	1.1 – 3.5	2.2
Sand, water saturated	1.5 – 4.0	2.4
Gypsum	1.3 – 2.8	1.6
Marl	1.5 – 3.5	1.8
Sandstone	1.3 – 5.1	2.3

Table B.1 Thermal Conductivity of Soil and Weak Rock

¹ DECC (2012) Microgeneration Installation Standard 3005: Requirements for contractors undertaking the design, supply, installation, set to work commissioning and handover of microgeneration heat pump systems, Issue 3.1a.

² Downing, R. A. & Gray, D. A. (1986) Geothermal energy – the potential in the United Kingdom. London, HMSO.

Formation	Number of Tests	Thermal Conductivity (W/mK)
London Clay – sandy mudstone	5	2.45 ± 0.07
Lambeth Group – sandy mudstone	4	2.33 ± 0.04
Lambeth Group – mudstone	10	1.63 ± 0.11
Chalk	41	1.79 ± 0.54
Upper Greensand - sandstone	18	2.66 ± 0.19
Gault – sandy mudstone	32	2.32 ± 0.04
Gault – mudstone	4	1.67 ± 0.11
Kimmeridge Clay	58	1.51 ± 0.09
Oxford Clay	27	1.56 ± 0.09
Mercia Mudstone	225	1.88 ± 0.03
Sherwood Sandstone	64	3.41 ± 0.09
Westphalian Coal Measures – sandstone	37	3.31 ± 0.62
Westphalian Coal Measures – siltstone	12	2.22 ± 0.29
Westphalian Coal Measures – mudstone	25	1.49 ± 0.41
Westphalian Coal Measures – coal	8	0.31 ± 0.08
Millstone Grit	7	3.75 ± 0.16
Carboniferous limestone	14	3.14 ± 0.13
Old Red Sandstone	27	3.26 ± 0.11
Hercynian Gneisses	895	3.30 ± 0.18
Basalt	17	1.80 ± 0.11

Table B.2 Thermal Conductivity Values for Selected UK Lithologies

B.3 Laboratory Testing

Most laboratory testing techniques for soils are based on establishing steady state conditions in the sample and measuring the temperature gradient and/or heat flow across the sample. In 2008 Clarke et al³ developed a testing method specifically for use with samples resulting from current UK site investigation practice. This method, available from testing laboratories in the UK is recommended for the laboratory testing of most soils and weak rocks.

An alternative method, based on more rapid transient techniques may also be used. The needle probe⁴ can be used either in the laboratory or in situ on site and involves pushing the probe into a specimen. The needle is then subject to a heat pulse and the resulting temperature changes are recorded and used to calculate the thermal conductivity. The principle of operation is identical to that of an in situ thermal response test, but the scale of the test is much smaller. The advantages of this method over the Clarke et al test are its speed and the ability to carry out testing in situ. Being transient the test is also less likely to cause moisture migration, which may affect the test result, in unsaturated soil. However, given the size of the needle (typically no more than a few millimetres) the test is only applicable in fine grained soils.

B.4 Volumetric Heat Capacity

Volumetric heat capacity for most minerals and impervious rocks is around $2.3 \text{ MJ/Km}^3 \pm 20\%$ ⁵. Given that water has a volumetric heat almost twice this (around 4.2 MJ/Km^3) and air around three orders of

³ Clarke, B. G., Agab, A. & Nicholson, D. (2008) Model specification to determine thermal conductivity of soils, Proceedings of the Institute of Civil Engineers, Geotechnical Engineering, 161, 161 – 168.

⁴ IEEE Guide for Soil Thermal Resistivity Measurements (1996) The Institute of Electrical and Electronics Engineers, Inc Std. 442-1981.

⁵ Roy, R. F., Beck, A. E. & Touloukian Y. S. (1981) Thermophysical properties of rocks, In: Touloukian, Y. S., Judd, W. R. & Roy, R. F. (eds) Physical properties of rocks and minerals, McGraw-Hill, New York.

magnitude less, then the phase proportions of a soils are important in determining the overall volumetric heat capacity.

Measuring volumetric heat capacity directly is extremely challenging⁶ and can lead to unreliable results. Rock fragments can be tested relatively rapidly and accurately according to the method of Scharlie & Rybach⁷. However, for soils, it is recommended to use the following equation based on the proportion of soil components:

$$S_{vc} = \chi_{solid} S_{vc(solid)} + \chi_{water} S_{vc(water)} + \chi_{air} S_{vc(air)}$$

where χ is the volume proportion of the phase component and S_{vc} is the volumetric heat capacity. Given the low value of $S_{vc(air)}$ it is common to neglect this phase.

⁶ Waples, D. W. & Waples, J. S. (2004) A review and evaluation of specific heat capacities of rocks, minerals and subsurface fluids. Part 1 minerals and non porous rocks. *Natural Resources Research*, 13 (2), 97 – 122.

⁷ Scharli, U. & Rybacj, L. (2001) Determination of specific heat capacity on rock fragments, *Geothermics*, 30, 93 – 110.

Appendix C: Soil Properties

C.1 Introduction

An attempt to address the seemingly conflicting experimental data on thermo-mechanical soil properties was the subject of a paper by Hueckel *et al.*, 2009¹. Further research is necessary in this area, however the following sections summarise the current understanding of the effects of heating and cooling soil.

C.2 Soil Classification

Fang and Daniels, 2006² reported that the plastic limit (PL) and liquid limit (LL) of a cohesive soil varies with temperature, proportional to the variation in viscosity of water with temperature. Water becomes less viscous at higher temperatures, corresponding to a reduction in plasticity index (PI) and liquidity index (LI) with temperature as confirmed by laboratory studies on different types of clay soils (kaolinite, illite and montmorillonite) carried out by Laguros, 1969³. Yilmaz, 2011⁴ showed that the changes in PI and LL between 20°C and 100°C resulted in a 15% drop in PL for kaolinite but a 10% increase in PL for bentonite (montmorillonite).

C.3 Stress History

The preconsolidation pressure of a soil is a unique value referring to the maximum value of vertical stress that a soil has experienced in the past, and is not affected by temperature. However, the apparent preconsolidation pressure separating the two linear portions of the compression curve (when plotted on a graph of strain or voids ratio versus logarithm of mean or vertical effective stress) has been found to be temperature dependent as shown in Figure C.1 (Eriksson, 1989⁵; Leroueil and Marques, 1996⁶; Cekerevac *et al.*, 2002⁷; Hueckel *et al.*, 2009).

¹ Hueckel, T., François, B. & Laloui, L. (2009), Explaining thermal failure in saturated clays, *Geotechnique* 59, No. 3, 197–212.

² Fang, H. And Daniels, J.L. (2006) *Introductory geotechnical engineering – an environmental perspective*, Taylor & Francis, London.

³ Laguros, J.G. (1969) Effect of temperature on some engineering properties of clay soils. In: Mitchell, J.K. (ed.) *Proceedings of International Conference on Effects of Temperature and Heat on the Engineering Behaviour of Soils*, Washington D C, USA, Highway Research Board, Special Report, 103, 186-193.

⁴ Yilmaz, G. (2011) The effects of temperature on the characteristics of kaolinite and bentonite, *Academic Journals, Scientific Research and Essays* Vol. 6(9), pp. 1928-1939, 4 May, 2011.

⁵ Eriksson, L.G. (1989) Temperature effects on consolidation properties of sulphide clays, *Proceedings of the twelfth international conference on soil mechanics and foundation engineering*, Rio de Janeiro, 2087-2090.

⁶ Leroueil, S. And Marques, M.E.S. (1996) Importance of strain rate and temperature effects in geotechnical engineering, SOA Report, *Measuring and modelling time dependent soil behaviour*, ASCE Geotech. Special Publication 61, 1-60.

⁷ Cekerevac, C., Laloui, L. & Vulliet, L. (2002) Dependency law for thermal evolution of preconsolidation pressure. In: Pande, G.N. & Pietruszczak, S. (eds) *Numerical Models in Geomechanics: Proceedings of the 8th International Symposium*, Rome, 687-692.

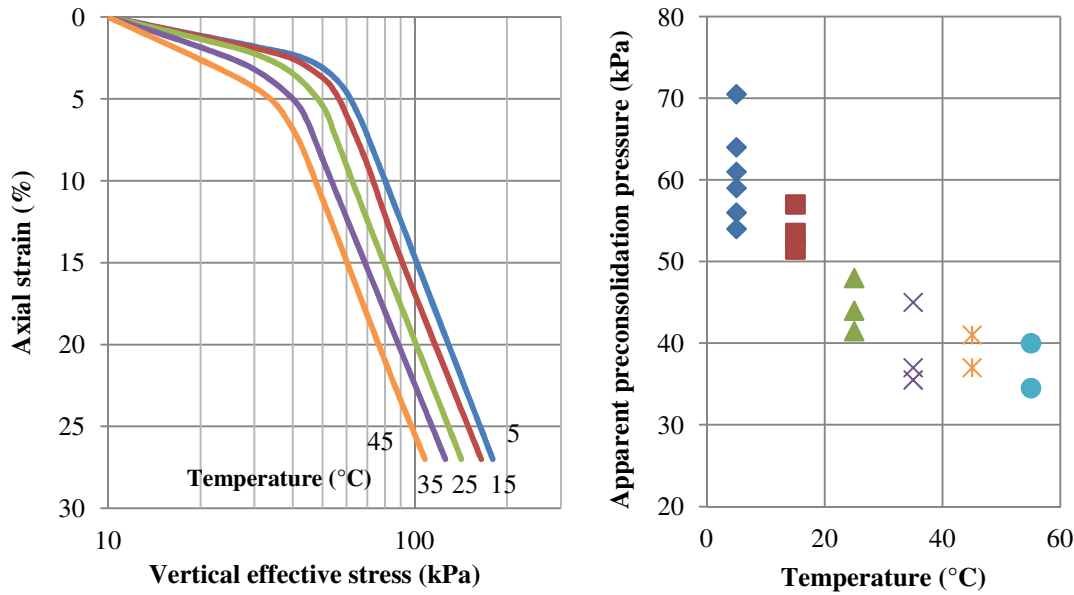


Figure C.1: Oedometer tests and calculated preconsolidation pressure showing variation with temperature (from Eriksson, 1989)

Several formulae describing the relationship between temperature and apparent preconsolidation pressure have been outlined by Cekerevac *et al.*, 2002 and are given below:

$$\sigma'_c(T) = \sigma'_c(T_0) \{1 + C [T_0 - T]\} \tag{1}$$

$$\sigma'_c(T) = \sigma'_c(T_0) \left[\frac{T_0}{T}\right]^{-0.15} \tag{2}$$

$$\sigma'_c(T) = \sigma'_c(T_0) \left\{1 - \gamma \left[\log \frac{T}{T_0}\right]\right\} \tag{3}$$

Where:

$\sigma'_c(T)$ = apparent preconsolidation at room temperature (20°C)

$\sigma'_c(T_0)$ = apparent preconsolidation at tested temperature

C = coefficient proposed by Boudali *et al.*, 1994⁸ = 0.009/°C

γ = coefficient proposed by Cekerevac *et al.*, 2002 = 0.075 (determined from isotropic triaxial tests on overconsolidated kaolin samples)

In all of the above formulae, a temperature increase is more critical than a temperature decrease. A temperature increase causes a reduction in apparent preconsolidation pressure and likelihood of increased settlements with the soil closer to plastic region of soil behaviour. For a 20°C temperature increase typical of the operating temperatures of thermal piles (15°C ± 20°C) the result is a reduction in apparent preconsolidation pressure of between 2% and 18%.

C.4 Strength

As noted by Leroueil and Marques, temperature has two major effects on soil strength:

⁸ Boudali, M., Leroueil, S. And Srinivasa Murthy, B.R. (1994) Vicous behaviour of natural clays, Proceedings of 13th International Conference on Soil Mechanics and Foundation Engineering, New Delhi, 411-416.

- Thermal expansion/contraction of porewater and soil structure.
- Modification of strength of contact between soil particles, including increased soil particle energy from increased temperatures resulting in increased likelihood of slippage between particles (Campanella & Mitchell, 1968⁹).

In non-cohesive soils the thermal expansion/contraction of porewater is not an issue due to the drained behaviour, and it is unclear whether the friction angle is unchanged or increases with increasing temperature (Hueckel *et al.*, 2009).

For cohesive soils, a reduction in the undrained shear strength with increasing temperature is expected. In the short term (undrained behaviour), thermal expansion of porewater is larger than the thermal expansion of the soil structure (Campanella and Mitchell, 1968), which together with the decreasing ability of clay to retain adsorbed water and therefore increasing volume of free water (De Bruyn and Thimus, 2002¹⁰) results in increasing porewater pressure with temperature. For constant total stress, the excess porewater pressure gives a reduction in effective stresses, resulting in decreased undrained shear strength. In the long term (drained), the voids ratio may increase for overconsolidated clay due to thermal expansion of the soil skeleton, whereas the voids ratio may decrease for normally consolidated soil due to plastic volumetric compression associated with the reduction in preconsolidation pressure. The undrained/drained shear strength after porewater pressure dissipation may increase or decrease depending on the stress history of the clay.

C.5 Stiffness

Several authors report a decrease in stiffness with increasing temperature (Highter, 1969¹¹; Leroueil and Marques, 1996; Fang & Daniels, 2006) as can also be inferred from the left hand graph in Figure C.1. This is an effect of the additional settlement caused by heating causing a reduction in voids ratio after drainage of excess porewater pressure. However, laboratory tests carried out after drained heating and consolidation have shown an increase in stiffness compared to the initial state of the soil due to the more consolidated state of the soil after heating (Hueckel *et al.*, 2009).

C.6 Example using London Clay

Section C.3 describes the change in soil properties due to changes in the apparent preconsolidation pressure, with a greater impact when the soil is at a stress state above the preconsolidation pressure. This effect is more relevant to normally consolidated soils than to overconsolidated soils. The following equations^{12,13} give an indication of the overconsolidation ratio (OCR, the ratio of preconsolidation pressure to the current vertical effective stress) representative of what could be expected for London Clay:

$$(c_u/\sigma'_v)_{nc} = 0.11 + 0.0037 PI \quad (\text{assuming } PI = 45\%, (c_u/\sigma'_v)_{nc} = 0.277) \quad (4)$$

⁹ Campanella, R.G. and Mitchell, J.K. (1968) Influence of temperature variations on soil behaviour, Journal of the Soil mechanics and foundations division, Proceedings of the American Society of Civil Engineers, Vol. 94, No. SM3, 709-734.

¹⁰ De Bruyn, D. and Thimus, J.F. (2002) The influence of a temperature increase on the mechanical and physical behaviour of boom clay in the framework of the geological disposal of high-level, heat emitting waste. In: Hoteit, N., Shao, J.F., Su, K. and Tijani, M. (eds.) Hydromechanical and Thermohydromechanical Behaviour of Deep Argillaceous Rock: Theory and Experiments, Taylor & Francis, 33-40.

¹¹ Highter, W. H. (1969) Temperature Effects on the Compaction and Strength Behavior of Clay. Publication FHWA/IN/JHRP-69/30. Joint Highway Research Project, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana.

¹² Skempton, A.W. (1957) Discussion on the planning and design of the new Hongkong airport, Proceedings of the ICE, 7(4), 305-307.

¹³ Ladd, C.C., Foott, R., Ishihara, K., Schlosser, F. And Poulos, H.G. (1977) Stress deformation and strength characteristics, Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, 421-494.

$$\text{OCR}^{0.8} = \frac{c_u / \sigma'_v}{(c_u / \sigma'_v)_{nc}} \quad (\text{assuming } c_u = 60 + 8z, \text{ at 15m depth OCR} = 6.2) \quad (5)$$

The value of OCR=6.2 can be used to look at the effect of temperature on soil stiffness based on the effects on axial strain shown in Figure C.1. With heating, the soil remains at the same value of vertical effective stress, but curve hops downwards to increased values of axial strain. The OCR value means that the current vertical effective stress is low compared to the value of preconsolidation pressure so that the reduction in preconsolidation pressure is not expected to drop below the vertical effective stress. The axial strain therefore remains at a low value on the first linear portion of the compression curve in Figure C.1 and the effect of temperature on London Clay is therefore not expected to be significant.

Appendix D: Load Transfer Mechanisms

Possible mechanisms explaining the load transfer effects on frictional pile are shown in Figure D.1 and are described below; assuming that temperature changes are uniform over the length of the pile, the two ends do not have any restraint and the pile expands and contracts about the mid-depth of the pile (Bourne-Webb et al.¹):

- i. Load only – The pile is in compression and moves downwards into the soil, with the shaft resistance acting in the upwards direction opposing the load.
- ii. Pile cooling only – If the ends of the pile are free to move, cooling results in contraction of the pile about the mid-point. Restraint to the pile shaft causes tensile stresses to develop within the pile. This may lead to cracking of the pile. The resulting shear stress on the soil pile interface in the same direction as that mobilised by compression loading in the upper part of the pile, and in the opposite direction in the lower part of the pile.
- iii. Load and cooling – The combined effect of load and cooling causes axial loads to become less compressive at the mid-point and may become tensile at the lower part of the pile. The mobilised shaft resistance increases in the upper part of the pile and decreases in the lower part of the pile.
- iv. Pile heating only – Heating causes the pile to expand about the mid-point, with shaft resistance causing additional compressive stresses to develop in the pile. The resulting shear stress on the soil pile interface in the opposite direction as that mobilised by compression loading in the upper part of the pile, and in the same direction in the lower part of the pile.
- v. Load and heating – A combined load and heating cycle results axial loads becoming more compressive. Restraint to the pile shaft causes compressive stresses to develop within the pile shaft. This may lead to compressive failure of the pile. The mobilised shaft resistance is decreased in the upper part of the pile but increased in the lower part of the pile.

The mobilisation of shaft resistance will produce pile heave during heating and pile settlement during cooling. The magnitude of the movement at the pile head depends on how the shaft resistance mobilise with relative displacement between pile and soil.

End restraints can change alter the response described above. For example, if thermal piles are surrounded by non-thermal piles and they share the pile cap or shaft at the top, there will be end restraint at the top. If the toes of the thermal piles are embedded in stiff ground, additional end bearing will develop especially in heating. Figure D.2 shows possible effect of heating on axial pile load and shaft resistance profiles. The end restraints will generally increases the pile stresses (tension in cooling and compression in heating) but decreases the magnitude of additional mobilised shaft resistance by thermal load.

¹ Bourne-Webb, P. J., Amatya, B., Soga, K., Amis, T., Davidson, T. & Payne, P. (2009) Energy pile test at Lambeth College, London: geotechnical and thermodynamic aspects of pile response to heat cycles, *Geotechnique*, 59 (3), 237-248.

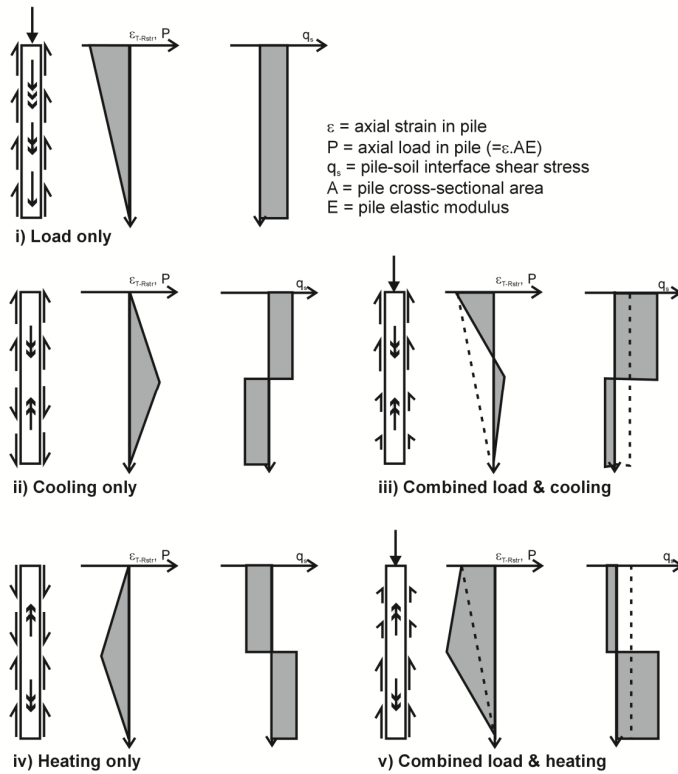


Figure D.1: Mechanisms for the response of piles to thermal loading with no end restraints and uniform mobilised shaft resistance (after Bourne-Webb et al., 2011²)

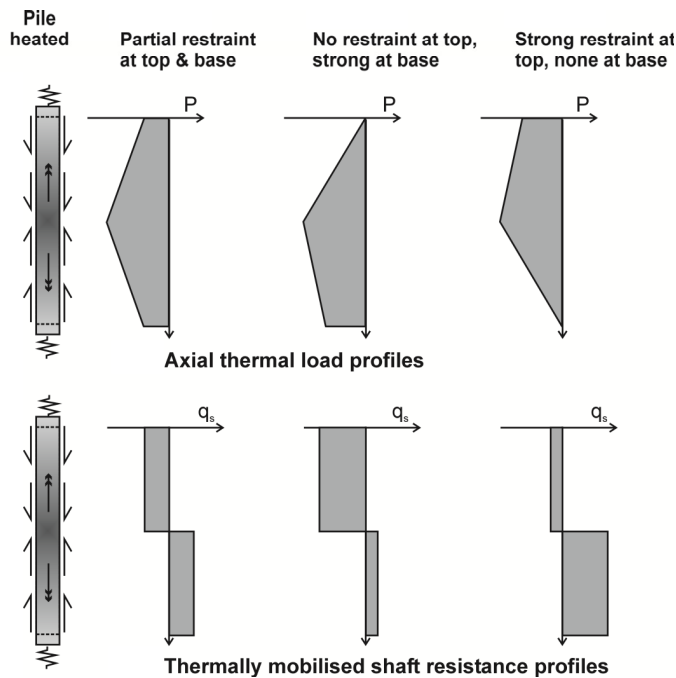


Figure D.2: Effects of end restraints on axial load and shaft resistance profiles (after Bourne-Webb et al., 2011)

² Bourne-Webb, P.J., Amatya, B. and Soga, K. (2011) A framework for understanding energy pile behaviour, Proceedings of ICE Geotechnical Engineering, available at: <http://dx.doi.org/10.1680/genq.10.00098>

Appendix E: SLS Effects to Consider in Pile Design

E.1 Pile Head Fixity and Thermal Expansion/Contraction Movements

A conservative estimate of pile movement can be made by assuming that the thermal strain is fully developed (i.e. no soil resistance) and fully restrained at the base. The additional movement will then be thermal strain x total pile length. This is a modification of the unrestrained pile movement shown in Figure E.1 (2) which shows no restraint at the base of the pile, so there is upwards movement at the pile head and downwards movement at the base.

In reality the pile will be restrained to some extent by the surrounding soil and a more realistic estimate of the pile movement can be made by comparing the effect of soil friction on the upwards moving portion of an expanding pile to the effects of downdrag^{1,2}. A more realistic estimate can also be made by using computer software that analyses the t-z load-transfer behaviour of the pile or by the use of finite element analysis (see Section 5.6.5).

It is also important to assess that the soil around the pile has not failed. The following checks can be made.

The end bearing pressure should be less than the design limit. A possible extreme case for the additional end bearing pressure by temperature change can be considered by assuming that the full additional thermal load evaluated is applied to the end bearing. It is noted that end movement will reduce the thermal load and hence this assumption can be very conservative.

The mobilised shaft friction should be less than the design limit. A possible extreme case for the additional mobilised shaft resistance by temperature change can be considered by assuming that the pile can fully expand at both ends with no movement around the middle as in Figure E1 (2).

E.2 Concrete Stress

Thermal expansion of the pile when it is heated leads to additional shaft friction constraining the heave movement in the upper part of the pile. This can lead to higher compressive axial compressive stress in the pile concrete. Similarly, the thermal contraction of the pile, when it is cooled, may lead to tensile stress in the pile. This additional stress should be calculated and allowed for in the assessment of the concrete stress design; however the movements caused by internal stresses are expected to be smaller than what the superstructure is able to tolerate. This affects the serviceability limit state (SLS).

The stress in the pile concrete should be less than the allowable limit. An extreme case for the additional concrete stress caused by temperature change can be considered by applying the full internally generated thermal load (Figure E1 (1)) with an assumption that the pile is fully restrained.

Figure E.1 shows the effect of end restraint conditions on pile movement and concrete stress at the two extreme conditions. In reality, unless only a proportion of the piles on a site are being used as thermal piles, the pile end conditions may be somewhere in between fully restrained and unrestrained.

A more realistic estimate of the concrete stress can be made by using computer software that analyses the load-transfer behaviour of the pile (see Section 5.6.5).

¹ Fellenius, B.H. (2006) Results from long term measurements in piles of drag load and downdrag, Canadian Geotechnical Journal, 43 (4), 409-430.

² Poulos, H.G. (2008) A practical design approach for piles with negative friction, Proceedings of the ICE: Geotechnical Engineering 161, Issue GE1, 19-27.

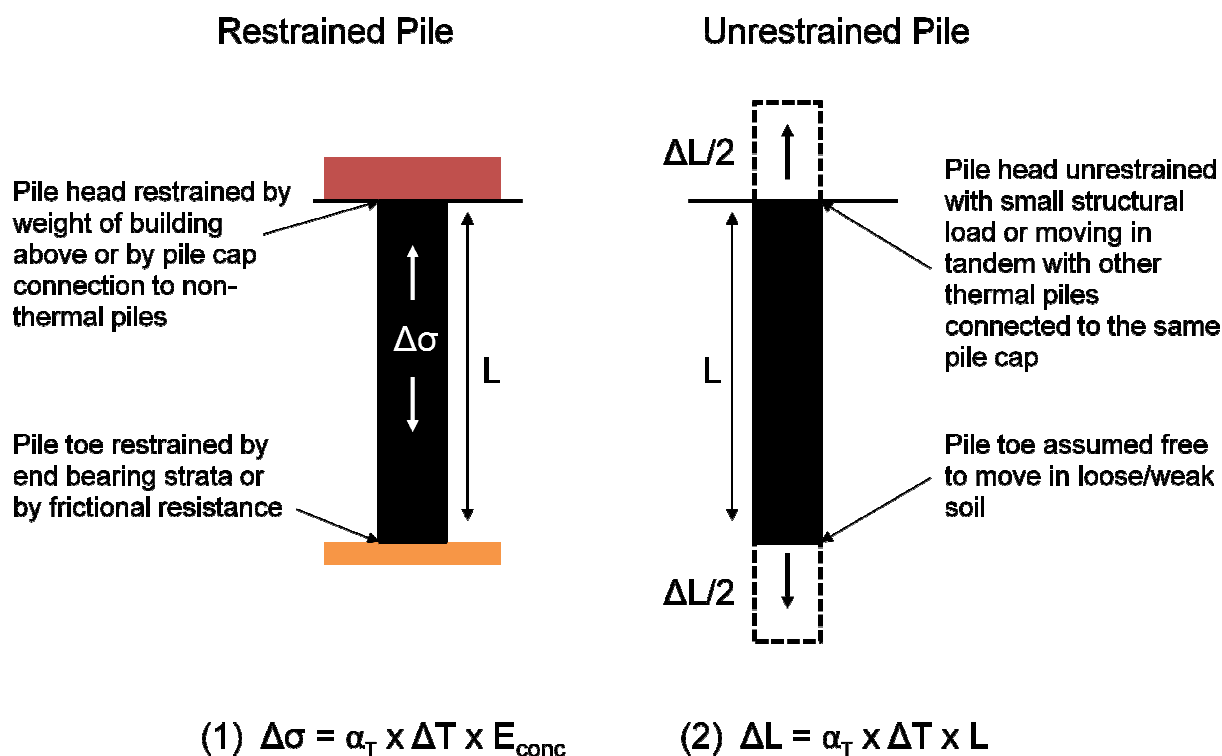


Figure E.1: Pile end restraint conditions

E.3 Cyclic Effects

The heating and cooling cycles can be daily or seasonal. It is likely that the season effects are large, up to approximately ± 15 to 20°C about the mean temperature with smaller daily cycles. However this is not always the case.

On certain structures such as off shore oil rigs or bridges the live loads can be a large proportion of the applied pile load. Cyclic loading of these live loads can result in accumulative movements. Design charts have been reproduced in Figure E.2 below from Poulos, 1989³ and Jardine and Standing, 2000⁴ for cyclic live load versus ultimate load effects. Another option is to follow the API method (API RP2A WSD) which considers maximum cyclic load in a static analysis but limits shaft friction to $0.7-0.9 \tau_s$ on the $t-z$ plot.

The charts in Figure E.2 provide an approximate and simplistic way of assessing the significance of cyclic loading by considering the cyclic live load (or in the thermal pile case, thermally induced cyclic load) as a proportion of the dead load (structural load on pile). For partially restrained piles such as at Lambeth College and seasonal cyclic loads over a 40 year design life (one cycle per year) the charts show that the pile cyclic behaviour is expected to be stable. For a typical pile loaded to approximately 50% of ultimate load (P_u or Q_{max} static on Figure E.2), the acceptable cyclic load can be read off the y-axis of the charts to be approximately 40%-50% of ultimate load for 40 yearly cycles.

There is an urgent research need in this area, which Cambridge are currently addressing with research into thermal-hydrological-mechanical (THM) models for use in modelling cyclic loading of thermal piles.

³ Poulos, H.G. (1989) The Mechanics of Calcareous Sediments, John Jaeger Memorial Lecture. Australian Geomechanics, Special Edition, pp. 8-41.

⁴ Jardine, R.J. and Standing, J.R. (2000) Pile load testing performed for HSE cyclic loading study at Dunkirk, Offshore Technology Report - OTO 2000 007, Health and Safety Executive, London.

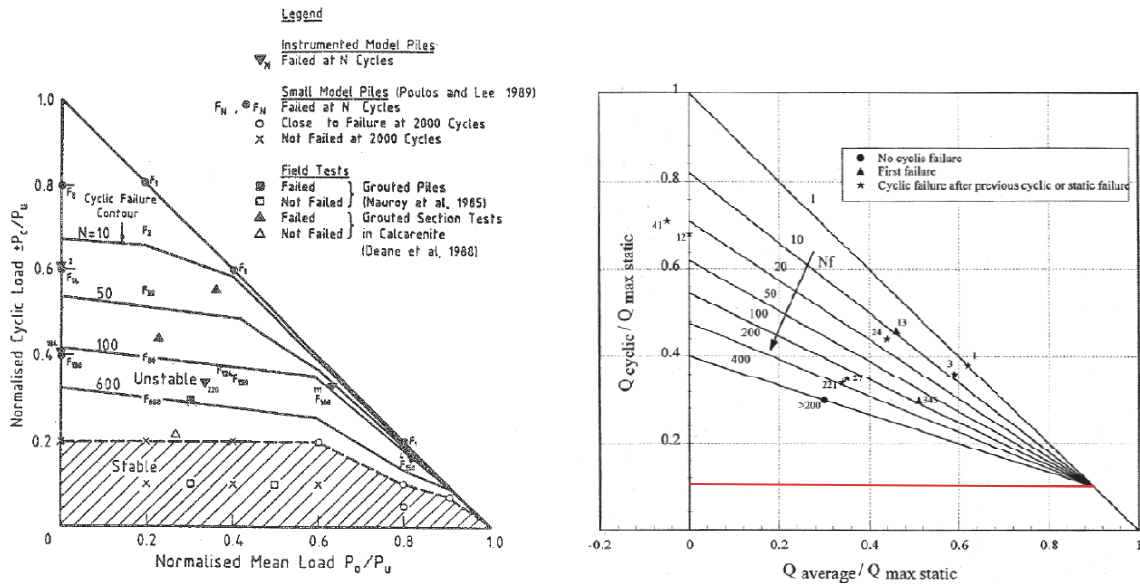


FIG. 12. Cyclic Stability Diagram

Figure E.2: Cyclic load interaction diagrams – Poulos (left) and Jardine and Standing (right)

E.4 Ground Temperature

It is important not to freeze the ground. Specifically, the temperature at the pile-soil interface should be kept above 0 °C. If it does, the pile-soil interface characteristics may change.

To avoid freezing the ground, monitoring of the flow temperature from the heat pump or control systems should be used according to the requirements of Section 14.0.

E.5 Other Effects

The pile can radially expand and shrink by heating and cooling. The surrounding soil can expand or shrink by heating and cooling due to thermal expansion of pore fluid as well as soil skeleton. This may influence the soil-pile interface characteristics and changes in radial stress, as well as the thermal heat transfer at the interface. Large diameter piles will have larger thermally induced displacement for a given change in temperature.

Appendix F: Design Charts

F.1 Introduction

The design charts in this appendix have been created using thermal pile software created by University of Cambridge. The software is based on a load transfer model similar to that proposed by Chow, 1986¹; Clancy & Randolph, 1993² and Chin & Poulos, 1991³. These charts have been developed based on a back analysis of a pile test in London Clay at Lambeth College. They should be used with caution in other geological conditions.

A number of assumptions and limitations should be noted when using the charts:

1. The soil stratigraphy in which the pile is situated is based on the estimated typical geology of a site in central London, assuming only the London Clay strata around the pile. Since consideration was given to the long-term behaviour of thermal pile, thermal effects were analysed with a drained analysis approach. Soil properties for the London Clay that were used in the software are listed below.

Undrained shear strength c_u (kPa)	$60 + 8z$ z is depth below top of pile, (m)
Drained Young's modulus (kPa)	$400 \times c_u$
Poisson's ratio, ν	0.2
Shaft friction coefficient, α	0.5
Shaft friction coefficient, β	0.8

2. The structural load on the pile was calculated based on the maximum working capacity of the pile following the guidance of the London District Surveyors Association, 2009⁴ and using undrained soil parameters (given above) as the limiting case. This guidance makes allowance for three factors of safety (2.0, 2.2 and 2.6) depending on the level of pile testing carried out.
3. Piles of varying length from 10m to 30m and varying diameter from 0.6m to 1.2m have been analysed using the software, by first applying a structural load equal to the pile working capacity, then applying 50 cycles of cooling and heating.
4. The thermal contraction and expansion of the pile due to the cooling and heating cycles affects the pile axial stress and pile head settlement as described in the following sections. The pile head was assumed to be free, with restraint to thermal expansion and contraction from the surrounding ground only. The assumed coefficient of thermal expansion of concrete used in the model is given below.

Linear thermal expansion coefficient of concrete, α ($^{\circ}\text{C}$)	8.5×10^{-6}
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5. The model includes the effects of thermal induced degradation in soil resistance and soil stiffness by adopting two empirical parameters D_T and δ respectively (Matlock and Foo, 1980⁵). In the current model, the soil resistance degrades by approximately 10% of its original value after a large number of cycles. The degradation of the soil stiffness depends on the normalised

¹ Chow, Y.K. (1986) Analysis of vertically loaded pile groups, International Journal for Numerical and Analytical Methods in Geomechanics, 10(1), 59-72.

² Clancy, P. and Randolph, M.F. (1993) An approximate analysis procedure for piled raft foundations, International Journal for Numerical and Analytical Methods in Geomechanics, 17(12), 849-869.

³ Chin, J.T. and Poulos, H.G. (1991) Axially loaded vertical piles and pile groups in layered soil, International Journal for Numerical and Analytical Methods in Geomechanics, 15, 497-511.

⁴ London District Surveyors Association (2009) Guidance notes for the design of straight shafted bored piles in London Clay, Guidance Note 1.

⁵ Matlock, H., and Foo, S.H.C. (1980) Axial analysis of piles using a hysteretic and degrading soil model, Proceedings of Conference Numerical methods in offshore piling, ICE, London, 127-133.

stress level, which varies with depth down the pile. At the highest values of normalised stress towards the top of the pile, the soil stiffness degradation does not exceed 5%.

F.2 Pile axial stress

Figure F.1 is a schematic showing the variation with depth of the axial stress within a typical pile. Under structural load only (and in the absence of other effects such as negative skin friction), the maximum axial stress is found at the pile head, reducing as load is transferred into the ground via shaft friction until the remaining load is transferred at the pile toe.

When the pile is heated, the pile tends to expand and axial stress builds up in the pile due to the restraint on movement from the surrounding ground. In some cases this leads to a maximum stress in the pile larger than the maximum stress from structural load, as shown on the schematic below.

When the pile is cooled, the pile tends to contract and axial stress reduces in the pile, again due to the restraint on movement from the surrounding ground. In some cases this leads to a minimum stress in the pile smaller than the minimum stress from structural load, as shown on the schematic below. This is important where the stress may be expected to change from a minimum compressive stress to a tensile stress towards the toe of the pile.

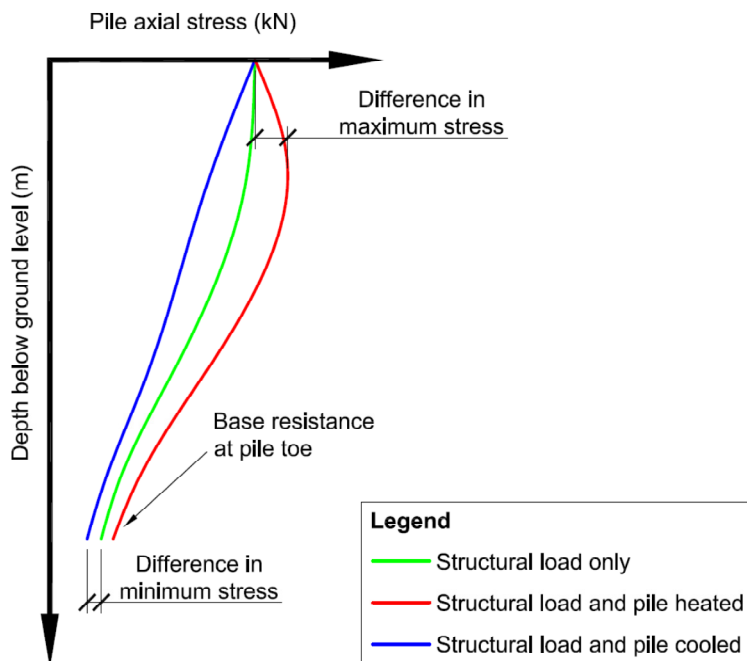


Figure F.1: Pile axial stress variation with depth

Based on the processes described above, charts of the addition or reduction in axial stress have been compiled and are presented in Figure F.2 for piles of varying dimensions. The way to use these charts is as follows:

1. First calculate the maximum and minimum stress in the pile due to imposed structural loading.
2. Make an assessment of the expected increase or decrease in pile temperature due to heating and cooling. E.g. 20°C heating implies that a pile at an ambient temperature of 15°C is heated to 35°C.
3. The charts then provide an approximation of the addition and reduction in stresses that can be expected due to thermal effects.
4. The charts show a range covering the scenarios where the factor of safety on the working pile capacity varies from 2.0 to 2.6. The lower values in the ranges shown can be used when FOS = 2.0, while the upper values should be used when FOS = 2.6.

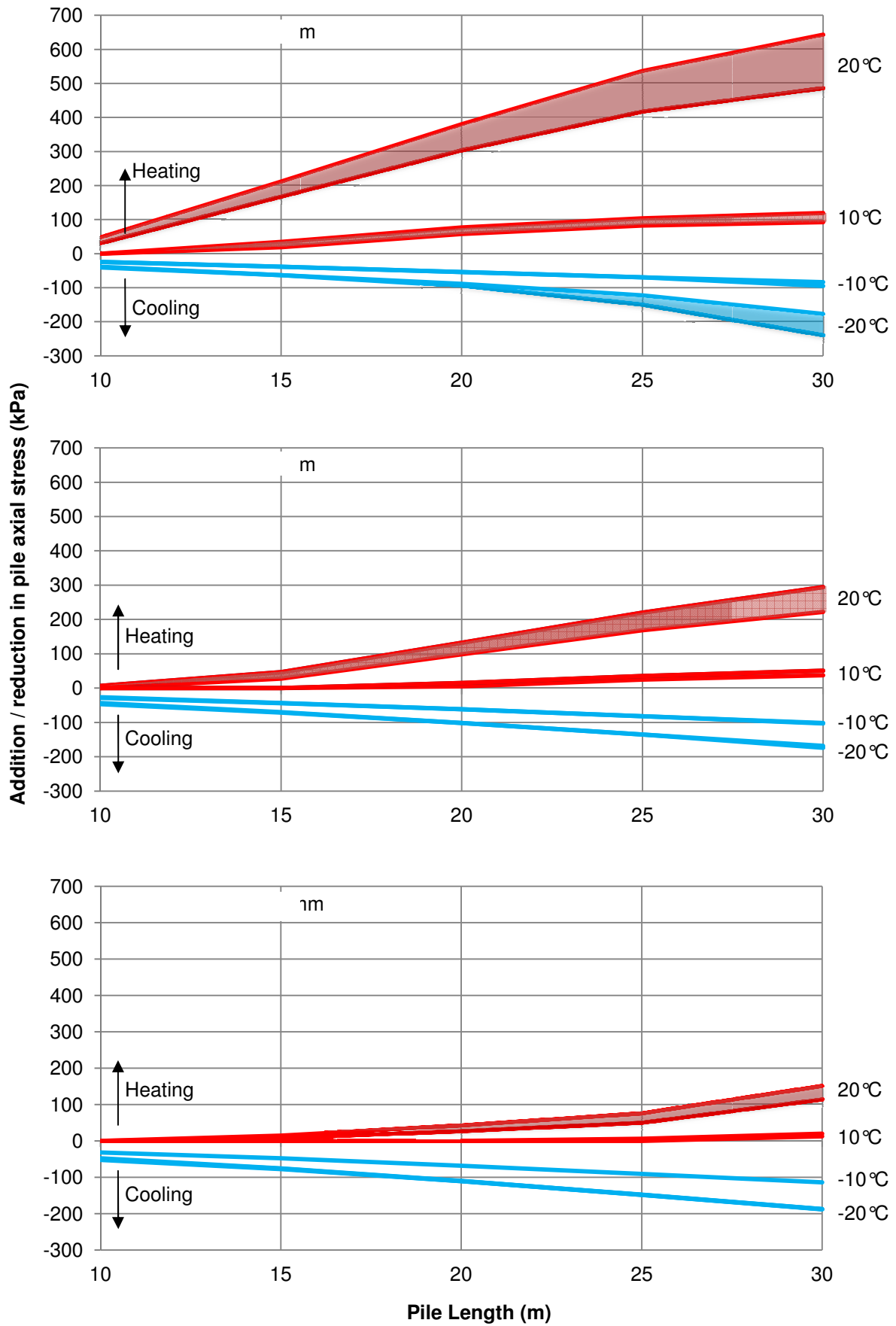


Figure F.2: Addition or reduction in pile axial stress for thermal piles

F.3 Pile head settlement

The diagram in Figure F.3 shows how pile head settlement is expected to vary with repeated heating and cooling cycles. After the initial settlement due to the application of structural load, further pile head movement is experienced due to thermal heating and cooling cycles. With the pile head assumed to be free, cooling of the pile results in additional settlement, while heating results in the pile head moving upwards. Repeated cycling of the thermal effects results in degradation of shaft friction along the pile, with accumulation of settlement.

Two settlement effects are assessed in this section as shown in Figure F.3:

1. Maximum additional pile head settlement, after settlement due to structural load and at the cooling phase. This can be added to the structural pile settlement to give an idea of the total pile settlement over the design life.
2. Maximum cyclic pile head movement due to heating and cooling effects. This is an indication of the seasonal movement of the pile head that can be expected.

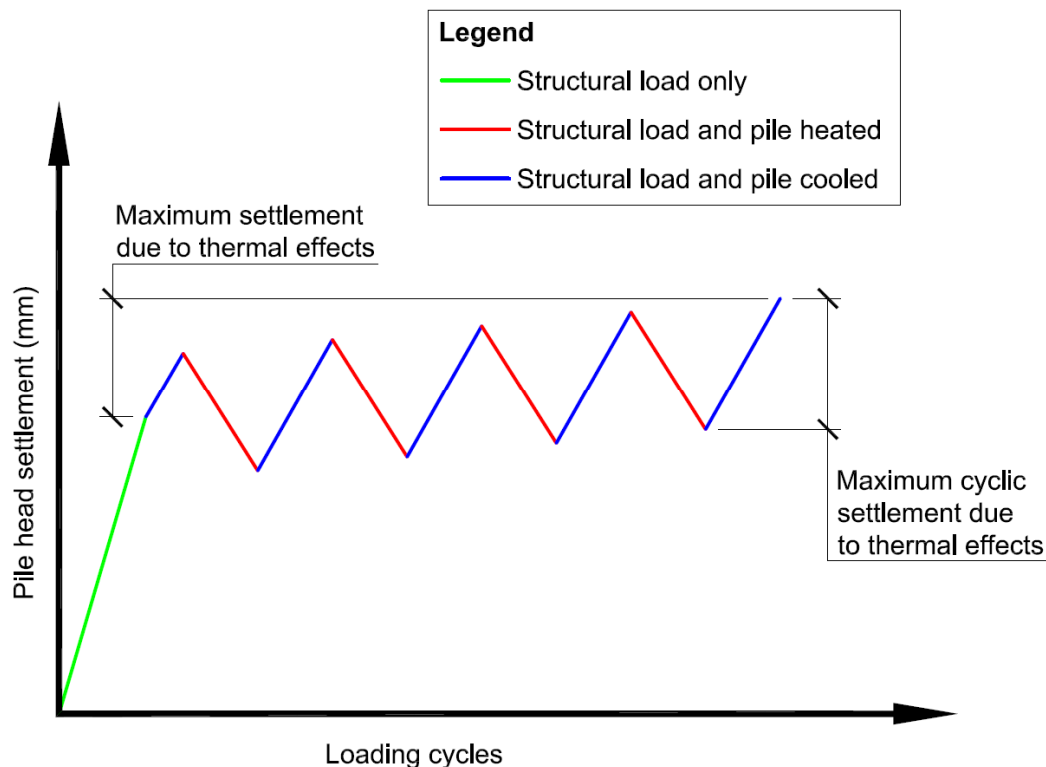


Figure F.3: Variation in pile head settlement with thermal load cycles

The results of a numerical study on various pile sizes shown in Figure F.4 and Figure F.5. The results were assessed considering 50 thermal load cycles to be typical of seasonal effects for a pile with a design life of 50 years. The temperature cycles are for both heating and cooling from ambient pile temperature, e.g. 10°C implies that a pile at an ambient temperature of 15°C is cooled to 5°C and heated to 25°C.

The lower values of pile head settlement / cyclic movement from the charts can be used for pile diameter of 600mm, while the upper values are for piles of 1200mm diameter.

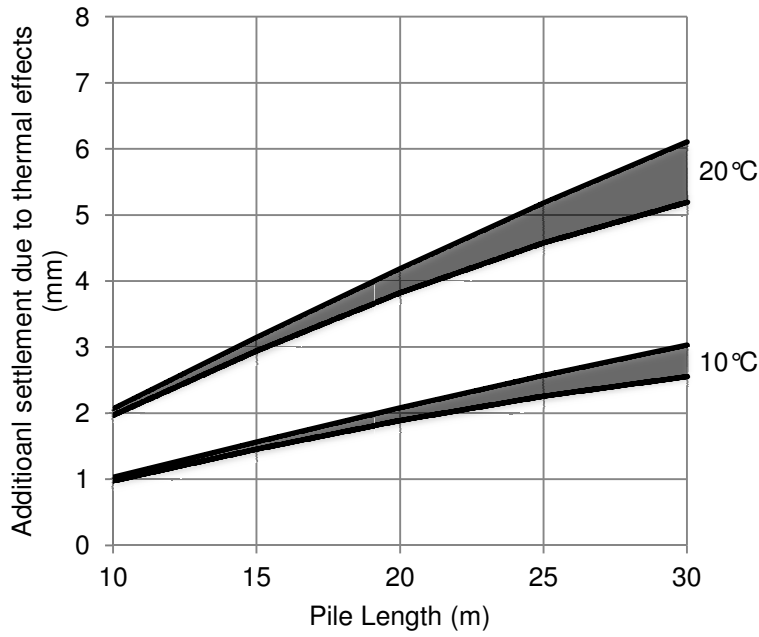


Figure F.4: Maximum pile head settlement due to thermal effects

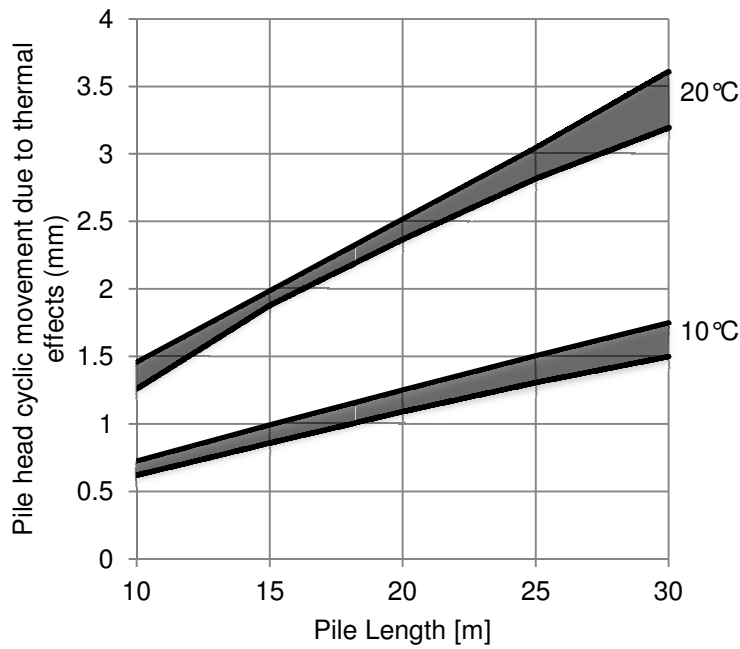


Figure F.5: Maximum cyclic pile head settlement due to thermal effects

Appendix G: Concrete Conductivity Annex

The thermal conductivity of concrete is a key material parameter in controlling the internal heat transfer behaviour of thermal piles. Along with the geometry it determines the thermal resistance of the pile when it is at a thermal steady state. There is a general impression that concrete has advantageous thermal properties which encourage heat transfer. However, the thermal conductivity of concrete can cover a wide range of values, from little over 1 W/mK to over 4 W/mK, depending on the mix design^{1,2}. Concrete thermal conductivity depends mainly on the aggregate lithology, aggregate volume ratio and water content². Concrete piles installed in clay soils or in any geological conditions below the water table are likely to be saturated. Neville¹ reports typical values of saturated concrete thermal conductivity between 1.4 W/mK and 3.6 W/mK. Piles installed in dry sands may have a lower thermal conductivity than these values owing to the reduced water content.

Many studies have considered the thermal conductivity of concrete, but few studies record all of the important variables (cement-aggregate ratio, aggregate type, moisture content). In addition cement replacement products can also affect the thermal conductivity. Assuming that pile concrete is typically saturated, the following sections consider the impact of the different variables on thermal conductivity before some recommendations are made about values for use with energy piles.

G.1 Aggregate Type

Concrete thermal conductivity is dependent on the thermal conductivity of its constituents. Consequently, aggregates which can range in thermal conductivity from 2 W/mK to 7 W/mK, play an important role in determining the overall thermal conductivity of the material. Typical concrete aggregates in order of their thermal conductivity are given in Table G.1 below. Quartz rich aggregate will lead to a higher thermal conductivity aggregate compared to limestone rich aggregate concrete. Many publications, e.g.^{1,2} give values for the thermal conductivity of concrete containing different aggregate lithologies (see also Table G.2), but without also providing details of the aggregate proportions it is not possible to compare these sources.

G.2 Cement Aggregate Ratio

Neat cement paste has a thermal conductivity of around 1.2 W/mK². Consequently, the higher the aggregate proportion in a concrete mix the greater thermal conductivity it will have. Figure G.1 plots the thermal conductivity of different concrete mixes where both the cement:aggregate volume ratio, and in most cases the aggregate lithology are known. The total aggregate volumes have been used in this assessment, i.e. both coarse aggregate and fine aggregate (sand).

For typical piling mixes high strength, and therefore high cement contents will be required. This means that pile concrete is likely to fall in the centre or on the left hand half of Figure G.1 depending on the cement:aggregate volume ratio. Although this may vary depending on the project specific requirements, 1:4 would be typical. It is also important to consider that the main coarse aggregate and the sand used in the mix may have different sources. The potential effect of this is highlighted in Table G.2 (although it should be noted that these data do not provide information pertaining to the overall aggregate proportions used).

¹ Neville, A.M. (1995) Properties of concrete, 4th edition. Longman, London.

² Tatro, S.B. (2006) Thermal properties, in: Lamond, J., Pielert, J. (eds), Significance of tests and properties of concrete and concrete making materials. Portland Cement Association, Skokie, Illinois, USA.

Rock type	Thermal Conductivity (W/mK) Range of quoted values
Quartzite	5.0 – 7.4
Dolomite/Dolostone	3.8 – 5.0
Siltstone	3.5 – 5.2
Sandstone	3.0
Granite (quartz monzonite)	2.8 – 3.6
Granite	2.5 – 3.8
Granodiorite	2.6 – 3.5
Amphibolite	2.6 – 3.8
Diabase (dolerite)	2.3 – 3.4
Gneiss	2.0 – 4.4
Limestone	2.0 – 3.0
Shale	2.0
Basalt	1.7 – 4.3

Table G.1: Aggregate Thermal Conductivities^{3,4,5,6}

Aggregate Type	Thermal Conductivity of Concrete (W/mK)	
	Sand and aggregate from same rock type	Aggregate from defined rock type with siliceous sand
Quartzite and siliceous gravels with high quartz content	2.9	2.9
Granite, gabbros, hornfels	1.4	2.0
Dolerite, basalt	1.3	1.9
Limestone, sandstone, chert	1.0	1.8

Table G.2: Thermal Conductivity by Aggregate Type⁷

³ Lane, D. S. (2006) Thermal properties of aggregates, in: Lamond, J., Pielert, J. (eds), Significance of tests and properties of concrete and concrete making materials. Portland Cement Association, Stokoe, Illinois, USA.

⁴ Clarke, S. P. (1966) Thermal conductivity, in Clarke, S., P., (ed) Handbook of physical constants, GSA Memoir 97, pp461 – 482.

⁵ Khan, M.I. (2002) Factors affecting the thermal properties of concrete and applicability of its prediction models. Building and Environment 37, 607 – 614.

⁶ Cote, J. & Konrad, J-M. (2005) A generalised thermal conductivity model for soils and construction materials, Canadian Geotechnical Journal, 42, 443 – 458.

⁷ Bamforth, P.B. (2007) Early-age thermal crack control in concrete, CIRIA 660, London.

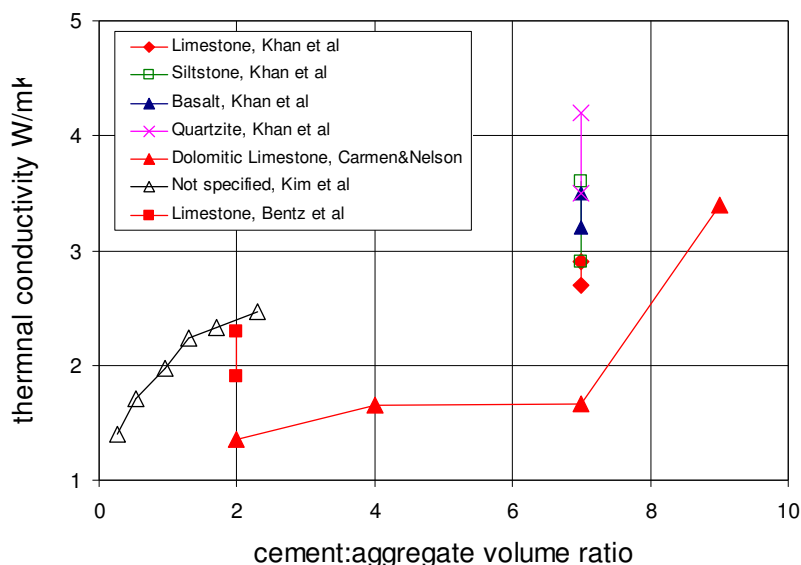


Figure G.1: Concrete Thermal Conductivity by Aggregate Type and Ratio^{8,9,10,11}

G.3 Cement Replacement Products

Figure G.1 and the foregoing text assume that no cement replacement products have been used. Recent studies^{2,3,12} have shown that use of fly ash or silica fume as a cement replacement will reduce the thermal conductivity of the concrete by up to 25% (Figure G.2). The effect of blast furnace slag is less conclusive, with smaller changes in properties observed.

Studies of heat transfer rates by Patel & Bull¹³ suggest that concrete mixes using fly ash as a cement reduction product will absorb more heat in a shorter time. This may be because, while the thermal conductivity is reduced due to the presence of the fly ash, the reduced density of the material results in a higher thermal diffusivity. Xu & Chung¹⁴ also attempted to determine appropriate mixes which would improve the thermal properties of concrete. They confirmed that the use of silica fume would reduce the thermal conductivity, but found that used in combination with small amounts of silane, both the thermal conductivity and the specific heat capacity would be increased. Silane has previously been used to coat admixtures, but is rarely used as an admixture itself. Inclusion of 2% silane was shown to increase the thermal conductivity by 38% and increase the specific heat by 50%. Given that many concrete mixes for pile applications use cement replacement products to improve workability, further research into the overall effect this has on heat exchanger effectiveness would be beneficial.

⁸ Carmen, A.P., Nelson, R.A. (1921) The thermal conductivity and diffusivity of concrete. University of Illinois, Engineering Experiment Station, Bulletin No. 122, April 1921.

⁹ Kim, K-H., Jeon, S-E., Kim, J-K., Yang, S. (2003) An experimental study on thermal conductivity of concrete. Cement and Concrete Research, 33, 363 – 371.

¹⁰ Bentz, D. P., Peltz, M. A., Duran-Herrera, A., Valdez, P. & Juarez, C. A. (2011) Thermal properties of high volume fly ash mortars and concretes, Journal of building physics, 34 (3), 263 – 275.

¹¹ Khan, M.I. (2002) Factors affecting the thermal properties of concrete and applicability of its prediction models. Building and Environment 37, 607 – 614.

¹² Demirboga (2007) Thermal conductivity and compressive strength of concrete incorporation with mineral admixtures, Building & Environment, 42 (7), 2467 -2471.

¹³ Patel, G. P. & Bull, J. W. (2011) Selection of material used for thermopiles for recycling heat within a building, Proceedings of Geo-Frontiers 2011.

¹⁴ Xu, Y. & Chung, D. D. L. (2000) Cement of high specific heat and high thermal conductivity, obtained by using silane and silica fume as admixtures, Cement and concrete research, 30, 1175 – 1178.

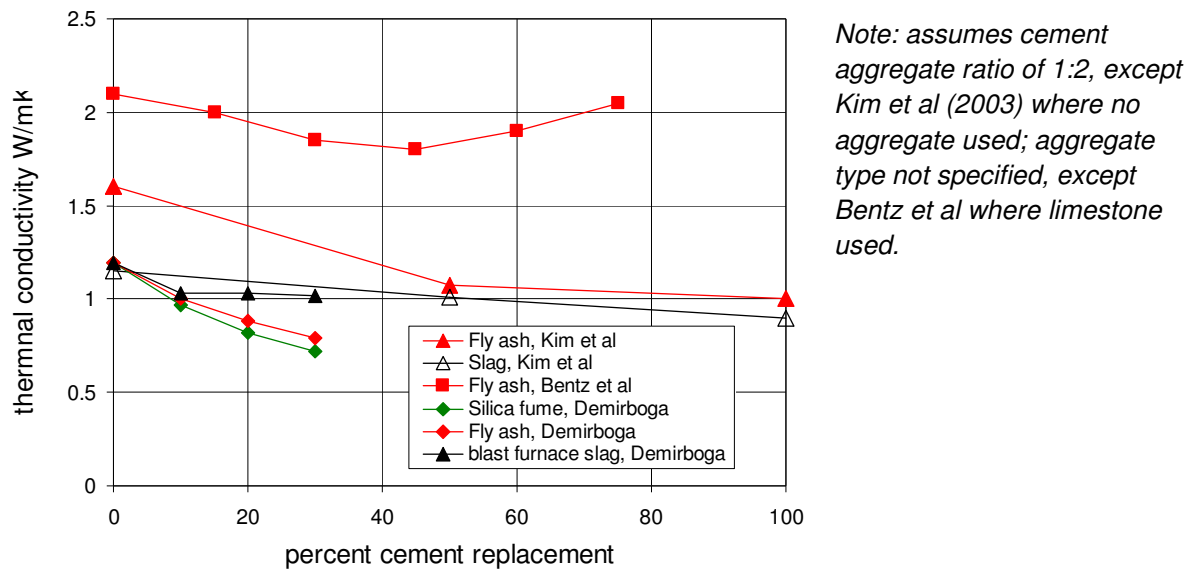


Figure G.2: Concrete Thermal Conductivity by Cement Replacement

G.4 Temperature Dependence

Thermal conductivity of concrete reduces with temperature¹⁵. The results present in the above sections consider testing at ambient laboratory conditions (around 20°C). Kim et al¹⁶ carried out testing in the range of 20°C to 60°C and found the results to vary by less than 0.2 W/mK within this range. More detailed studies have shown the variation in thermal conductivity to be proportional to temperature within the range of -20°C to 100°C¹⁷. The proportionality constant is not influenced by the type of cement but is dependent on the type of aggregate. Values up to around -0.004 W⁻¹ were reported. This is consistent with the Kim et al results and suggests a potential variation of less than 0.2 W/mK over the range of operation of ground energy systems. This is likely to be less in magnitude than uncertainties relating to other factors.

G.5 Recommendations

Based on the proportion and type of aggregates likely to be used in pile concrete mixes, it is unlikely that the thermal conductivity would be in excess of 2.5 W/mK. In many cases, with low thermal conductivity aggregate, low aggregate ratios and the presence of admixtures, the value may in fact be much lower. Consequently, for conservative design purposes, with no recourse to specific testing, values less than 1.5 W/mK are recommended. Where the aggregate is known to be siliceous, with a cement : aggregate volume ratio of at least 1:4, then larger thermal conductivities, in the range 1.5 W/mK to 2.0 W/mK may be used.

¹⁵ Morabito, P. (1989) Measurement of the thermal properties of different concretes, High Temp. High Press., 21, 51 – 59.

¹⁶ Kim, K-H., Jeon, S-E., Kim, J-K., Yang, S. (2003) An experimental study on thermal conductivity of concrete. Cement and Concrete Research, 33, 363 – 371.

¹⁷ Morabito, P. (2001) Thermal properties of concrete. Variations with the temperature and during the hydration phase, Department of Civil and Mining Engineering, Lulea University, Report BE96-3843/2001:18-4.

Appendix H: Thermals Loops in Pile / Wall Cover Zone

Thermal loops would ideally be fixed to the inside of the reinforcement cage when installed in piles / walls in order to maintain the full concrete cover to reinforcement and to protect the loops from damage as much as possible. However it is important to minimise joints in the system and as transport and site constraints often mean that pile / wall cages are installed in separate sections, it is not always possible to install loops in this location. In the case of reinforcement cages being spliced together during installation, thermal loop pipework can be installed on the outside of the pile / wall cages and tied to the reinforcement as the cage is lowered into the bore / trench. It is also important to maximise the efficiency of the ground source heat pump system by placing the thermal loop pipes as close as possible to the soil zone, in which case pipes are fixed to the outer side of the pile / wall reinforcing cage.

To satisfy durability requirements the concrete composition should be selected to satisfy the local ground conditions and the reinforcement is then protected by the concrete with an appropriate thickness (cover). In non-aggressive, low chloride ground this is normally specified as 75 mm in order to guarantee a minimum cover of 25 mm cover plus 50mm allowance for deviation. Further details on the cover requirements in the UK are given in BS 8500-1:2006.

Pipes used for thermal loops can have an outside diameter of up to 35 mm and when fixed to the outside of the cage should be fixed to the link reinforcement and therefore occupy the inner part of the typical 75 mm cover zone. In addition the pipes should be fixed clear of vertical reinforcing bars ensuring bond of the main bars is unaffected. It should also be noted that plastic spacers and installation guide skids will be present in this zone as a matter of course.

Following pouring the concrete section will be at risk from cracking caused by shrinkage and deflection under load. As the section is below ground, any significant drying is unlikely and the risk of shrinkage cracking is low. This is so even following excavation where piles are installed as part of a retaining wall and the inner face is exposed, as the diaphragm or piled wall is covered with a concrete lining wall or drained cavity. The risk of shrinkage cracking is further reduced by any axial compression in the piles / wall and by vertical joints where present. Vertical joints between panels are unreinforced and it is likely that any movement would occur at these locations rather than crack the wall. If a vertical crack did develop in the pile / wall it would be likely to occur at the location of the pipe but the crack would be controlled by the horizontal reinforcement.

When the pile / wall section resists the soil pressures following excavation it is likely the section will exhibit horizontal flexural cracking on the outside face in areas of hogging, which will occur at horizontal prop locations. This cracking is expected and longitudinal reinforcement is provided to control distribution and crack width. This should be controlled to suit the durability requirements of the project design standards. The introduction of vertical pipes fixed to the link bars and clear of the vertical bars will have no adverse effect on the likelihood of transverse shrinkage or flexural cracking in the section.

The principal degradation factors to be considered for the pile / wall are the risk of chemical attack from aggressive groundwater, and corrosion of embedded reinforcement:

- Chemical attack from groundwater is a surface action on the concrete itself and the concrete is designed to be resistant. The pipes are buried within the concrete hence their presence will have no direct influence on chemical attack from groundwater.
- Corrosion of reinforcement in concrete can only occur if the normal protective passive oxide layer is broken down either by carbonation of the concrete or by a build-up of chlorides through ingress from the groundwater. Where no appreciable concentration of chlorides is expected in the groundwater, the risk of chloride-induced reinforcement corrosion is insignificant, regardless of the presence of the embedded pipes.

For buried concrete, protection against carbonation-induced corrosion of reinforcement requires a minimum cover of only 25mm even for a 120 year design life. The typical specified nominal cover is

75mm to allow for casting directly against soil. In practice carbonation of buried concrete is usually negligible.

In the extremely unlikely event that corrosion initiation conditions exist such as in areas of high chloride concentration in groundwater, then the rate of corrosion of embedded reinforcement will be controlled by the availability of oxygen. Beneath about 1m below ground level in natural ground, or below groundwater level, there is insufficient oxygen available to support significant corrosion even should the passive oxide layer be destroyed by carbonation or chloride ingress, as seen from the extracts below:

“For the general case of reinforcement within a fully embedded pile, ready access to oxygen is restricted to perhaps the upper metre or so from the ground surface through shrinkage cracks, worm holes, etc.” [Transport Research Laboratory Report (TRL) 144 ‘Design of Reinforcement in Piles’]

“For the general case of a fully embedded wall in non aggressive ground..., ready access to oxygen is restricted to a distance of one metre below the surface of formation level of the excavation below which naturally occurring ground surrounds the element.” [Highways Agency (HA) ‘Design Manual for Roads and Bridges’]

“As the water content of concrete increases, the rate of oxygen diffusion decreases. In totally saturated concrete diffusion is too slow for corrosion to take place even if the passive layer at the surface of the reinforcement has been destroyed.” [Building Research Establishment Report BR 255 ‘Performance of building materials in contaminated land’]

The presence of the embedded pipes, or their influence on cracking of the concrete, will have no effect on chloride or carbonation conditions within the ground, nor on oxygen availability, therefore will not increase the likelihood of reinforcement corrosion.

Therefore the introduction of vertical thermal loop pipework in the pile / wall section is not expected to affect the durability of the section. In terms of the pipe itself, products using the same material are used as waterproof membranes, linings for landfill sites and more particularly as ducts in post-tensioned highways structures requiring 120 year design life. However it is recommended that assurance is received from the manufacturers that the durability of the pipes is compatible with the life of the structure.