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Session 1 Report: Identifying Best Practice, Installation, Laboratory Testing, and Field Testing

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This paper summarizes recommendations for best practice associated with the installation of geothermal loops within foundations to form thermo-piles, based on experience gained over the past 10 years in the UK. The issue of paramount importance in constructing a successful thermo-pile installation is the early stage coordination with all parties that will encounter, install, or test the geothermal loops. Several lessons learned from the installation and construction of thermo-piles are described to help ensure a smooth installation process. As long as there is early coordination, the installation of geothermal heat exchange tubing is relatively simple and will have very little or no impact on typical deep foundation installation procedures. This, coupled with the fact that there are additional costs and implications associated with other geothermal heat exchange approaches, implies that thermo-piles are an ideal economic solution to access a renewable energy source.

1. Introduction

The installation of geothermal loops into UK building foundations has continued to gather pace over the past 10 years (Amis and Loveridge, 2014), as well as in other countries (Brandl, 2006). Initial concerns over the potential to affect structural reliability have largely been answered, thanks to some detailed field monitoring studies (Brandl, 2006; Laloui et al., 2006; Bourne-Webb et al., 2009; Bouazza et al., 2012; Amatya et al., 2012; McCartney and Murphy, 2012; Olgun et al., 2012; Murphy et al., 2014a; Murphy et al., 2014b) and numerical simulation studies (Laloui et al., 2006; Knellwolf et al., 2011; Wang et al., 2012; Ouayng et al., 2012) undertaken by various researchers around the world. Further, the thermal response of thermo-piles has been well established, both from the perspective of thermal conductivity characterization (Hamada et al., 2007; Gao et al., 2008; Lennon et al., 2009; Brettman and Amis, 2011; Ozudogru et al., 2012; Olgun et al., 2012; Loveridge and Powrie, 2012; Murphy et al., 2014a; Murphy et al., 2014c) and long-term thermal response (Brandl, 2006; Ooka et al., 2007; Wood et al., 2009; Adam and Markiewicz, 2009; Wood et al., 2010; Murphy and McCartney, 2014). Studies such as Loveridge and Powrie (2013) have performed analyses required to incorporate the geometry of the heat exchange system for thermo-piles into commonly-used building simulation programs such as EnergyPlus (Crawley et al., 2001).

Overall, the structural and thermal studies on thermo-piles confirm that they can provide a functional approach to access geothermal energy. In addition, there are significant benefits to using structural foundations for heating and cooling buildings when compared to installation of other ground source systems. Firstly, as the foundations are a necessity to the future building, attaching geothermal loops to the reinforcement cages needed as part of the structural requirement, as shown in Figure 1, should add virtually no additional construction time as long as the activity is coordinated carefully. Secondly the placement of loops within foundation piles is considerably more economic than forming purpose drilled boreholes that will only add another construction activity into the overall project.

Since the introduction of recent UK government incentives and planning laws for renewable heat energy, coupled with economic improvements, it is expected that the use of thermo-piles will provide a significant amount of heating and cooling to the very building it is supporting. Further, it is likely to see an acceleration in the use of this type of renewable technology due to the incremental cost over that associated with installing a deep foundation system. Developers increasingly look at ways of meeting ever tightening energy saving requirements and CO_2 reduction targets.

GI Energy, having installed the majority of UK's commercial ground-source heat pump (GSHP) systems and most of the thermo-pile installations, worked very closely with the UK's Ground Source Heat Pump (GSHP) Association in developing a Thermal Pile Standard that incorporates many years of design, installation and materials knowledge combined with lessons learnt from full-scale installations in buildings (GSHP Association, 2012). The intent of the standard was to recommend best practice derived from the many trials and projects undertaken in the past 10 years. Foundation contractors in the UK have to deal with a multitude of ground conditions that each requires a different technique to form an economically and structurally sound foundation. Across the UK there are many examples of geothermal loops having been incorporated into every type of foundation, including:

- Small-diameter (i.e., $\leq$ 600 mm) rotary bored piles at Westminster Academy
- Large-diameter (> 600mm) rotary bored piles, One New Change London / Crossrail
- Piles constructed under drilling fluids - Bankside London
- Continuous flight auger (CFA) piles – London Bridge Station /Cambridge Offices/ Belfast Police Station
- Driven cast in-situ piles – North Kent Police station
- Driven precast piles – Balmore Glasgow
- Diaphragm walls – Bulgari Hotel Knightsbridge / Crossrail Stations

In each project and pile type it is important to understand the 5 main challenges encountered during the installation of geothermal heat exchangers into deep foundations. These include (1) understanding responsibilities; (2) introduction of loops into the pile cage; (3) effects of the piling installation method (4) protection of geothermal loops during installation; and (5) evaluation of geothermal loop integrity at all times. The following sections include further detail on each of these challenges.

2. Understanding Responsibilities

It is beneficial for a GSHP specialist to be involved with a project team from the earliest possible stage prior to a project being presented to Planning Authorities for approval. Firstly, identify the most appropriate ground-source solutions for a proposed project. Secondly, and most importantly, provide the value engineering that will identify the most appropriate solution with the best returns on investment and annual CO_2 and run costs savings, in order to clearly identify the best solution. The GSHPA Thermal pile Standard (GHSP Association,

2012) sets out clear guidance on roles and responsibilities during the various stages of the project, as shown in Figure 2.

The GSHP specialist's role is a lengthy one. When a thermo-pile solution is proposed, it will require more coordination with key parties to ensure that the construction program remains unaffected and additional costs are minimized. Prior to commencing work on site it will be necessary to interact, coordinate, and gain agreement with the various consultants:

- The geotechnical engineer designing foundations, into which geothermal loops will be installed,
- The structural engineer designing pile caps and basement slabs into which geothermal loops will have to be installed to connect loops in piles to the plant-room.
- The mechanical and electrical engineer designing heating and cooling distribution within the building.
- The building management control specialist.

Once this initial stage, which typically can last between 12 and 18 months is completed, and clear deliverables have been approved with the team and the planning authorities, the focus of the project moves on to delivery mode. Again, early coordination is important, this time with the site team specifically:

- The piling contractor to ensure loops will be satisfactorily installed to the depths required within the pile
- The various ground workers and contractors that will be excavating and forming pile caps and slabs within which loops will need to be incorporated and fed back to the plant room to ensure maintaining geothermal loop integrity at all times is paramount.
- The next stage will be to integrate and coordinate with the services team installing the buildings heating and cooling system and also the building management team.

Thus from this brief synopsis of the level of involvement of a GSHP specialist in the installation of a thermo-pile system, it is important to clearly identify from an early stage with the GSHP specialist. The following issues need to be established in advance in order to ensure a smooth design and installation process:

- Contractual relationship between different parties
- Agree scope and responsibility for each stage of work
- Coordinate with all parties as early as possible this will help to
    - Evaluate critical points (installation and connection levels)
    - Assign system redundancy levels associated with each key stage of the project
    - Carry out appropriate risk assessment

3. Introduction of Loops into the Pile Cage

There are many different piling techniques that can be used for dealing with different ground conditions. Most piling techniques incorporate steel reinforcing cages to address the structural capacity of the foundation system. The logical and economical step is to attach the geothermal loops to the reinforcing cage. However, consideration needs to be given to the following aspects:

- Is the design of the reinforcing cage robust enough to cope with transportation, lifting, and installation of the thermo-pile? It is critical to avoid excess deflection of the cage which may damage the geothermal loops.
- Will the geothermal loops be fabricated on or off site? This is a critical aspect to prevent leaks. Fusion welding or butt welding is best under controlled conditions. Accordingly, prefabricated bullet type shoes at base of loops, as shown in Figure 3, are a commonly used approach.
- What type of fixings is to be used to attach geothermal loops to the reinforcing cage? It is critical to install sufficient fixity to prevent the geothermal loops from bending or choking.
- How will the potential for the geothermal loops 'float' in wet concrete be considered? To address this issue, additional weight of steel may be required.

4. Effect of the Piling Technique on the GSHP System

Each piling technique has its own method for installing geothermal loops that needs consideration from a GSHP perspective. The role of the different piling techniques is summarized as follows:

4.1. Rotary Bored Piles

In most cases the reinforcement cage is not needed to extend the full depth of the pile and is placed into an empty bore prior to concreting. In this case geothermal loops can be installed within the cage and allowed to suspend below the cage such that loops are allowed to maximize the full depth of the pile. A small amount of additional reinforcement will be required at the base of the loops to prevent any flotation of the loops during concreting. Care needs to be exercised if using a tremmie pipe such that loops do not become damaged during concreting of the pile. A picture of a thermo-pile being installed in a rotary bored pile at Westminster Academy is shown in Figure 4. This project involved 260 rotary-bored piles with depths ranging from 15-20 m, and is designed to deliver 331 kW of heating and 120 kW of cooling.

In some cases, rotary bored piles are designed to cater for tension loads. In this case it is likely that full length reinforcement will be specified. A picture of a full-length welded reinforcing cage being installed at One New Change London is shown in Figure 5. This project involved 219 thermo-piles that were 40 m deep, with diameters ranging from 1.8 to 2.5 m. The system is designed to provide 1638 kW of heating and 1742 kW of cooling. In the case that a full-length cage is needed, a method needs to be agreed between GSHP contractor and piling contractor on how loops are to be attached to the reinforcement cage as it is likely to be installed in several sections, as shown in Figure 6. Loops can be installed on the inside or outside of the reinforcement cage. In the case of the project at One New Change London, the reinforcing cages were prefabricated in three sections. One continuous length of geothermal loop was preinstalled within the top cage of each pile, as shown in Figure 7(a), and transported to site. At the site they were raised in the air then fed through and attached to the lower sections of the cage as shown in Figure 7(b). To connect the loops to inside face of lower cages, the entire 35 m long cage was lifted out of pile and bundled loops were fixed to inside face of cage and then lowered into the correct position. The loops were filled with water and pressure tested prior to concreting works.

Alternatively loops can be installed on the outside face of the reinforcement cage as it is being installed using loop reelers, as shown in Figure 8 for a project undertaken at Bankside Project London. This technique is suitable also for attaching loops to the soil retained side of diaphragm wall cages as recently carried out at various Crossrail Station projects in central London. In most cases, through careful coordination, the addition of geothermal loops to piling and follow-on works have minimal impact on the work's program.

4.2. Driven Cast In-situ Piles (DCIS)

DCIS piles are perhaps the most straightforward of piles to incorporate geothermal loops into. Due to the construction methodology it is necessary to incorporate a single piece of reinforcement the full length of the pile to prevent "necking" of the concrete during casing extraction. It is this single piece of reinforcement bar that can be used in this technique on to which geothermal loops can be attached as seen below on a project at Gravesend in Kent, shown in Figure 9. The Consulting Engineer requested 100% resilience, on this project hence the second loop shown in the picture, which incidentally was not needed, as there were no loop failures during construction program.

4.3. Continuous Flight Auger Pile (CFA)

Over the past 10 years the CFA technique has dramatically entered areas where many other piling techniques were the norm. This is due to significant advances of computer equipment being able to monitor concrete flow and pressure during auger extraction to verify pile quality. In order to install geothermal loops within this type of pile it is necessary to provide an additional piece of reinforcement that can deliver the loops as deep as possible within the constructed pile, as shown in Figure 10(a). Trials have been undertaken across the UK where loops have been installed up to 28 m (Newcastle) and 22 m (Cambridge). However, the economics of installing loops on 40/50 mm reinforcement bars to such depths, coupled with the risk of being able to push geothermal loops into concrete at these depths means it is wise to carefully consider the following questions:

- What is feasible and consider limiting depth to a single piece of reinforcement?
- CFA concrete mix remains fluid and not likely to flash set?
- What are the problematic site geology conditions for loop installation? For example dense sand bands can cause concrete to stiffen quickly making loop insertion difficult; other concerns?
- Will there be a handling crane to install loops? If so, then have loops ready suspended for insertion before augers have completed the pile, as shown in Figure 10(b).
- Will a vibrator be available to help get the loop to the desired to depth? It is important to avoid mechanical surging (i.e., do not hammer down with excavator)

4.4. Precast Piles/Driven Steel H sections

Various trials both in the UK and US have shown that it is possible to attach a geothermal loop to the outer face of a precast pile or driven H section and drive it to depth without damaging the loop. A total of twenty 18 m-deep precast driven piles were installed with geothermal loops attached as a trial in Balmore, Scotland. For the past 5 years they have been providing 12 kW of heating to a changing/drying room for operatives at a precast manufacturing plant. To date, this type of thermo-pile has not been installed on a commercial or housing project, but is certainly a viable solution.

5. Protecting Geothermal Loops

It is essential that loops are suitably protected from damage from the moment they arrive on site. Loop ends must be marked up with lengths, pile numbers, and destination along with certification of pressure test to verify U bend fusion, as shown in Figure 11. Loops ideally should be prefabricated to specified lengths off site under factory conditions where possible to maintain a high standard of quality. It is essential to ensure loops remain capped at all times, as foreign objects such as particles of sand, cement, grout entering the loops can result in additional time and costs on site trying to unblock the loops. Geothermal loops within the pile trim zones should be protected with debonding foam in the same way as reinforcement, as shown in Figure 12. Additionally, either rigid plastic or steel sleeves are recommended to prevent mechanical damage from pile trimming, as shown in Figure 13. The ground worker should be included in discussions on how piles are to be trimmed and the additional care needed to maintain loops.

6. Evaluation of Loop Integrity at All Stages of Construction

There are 3 main periods when geothermal loops are most susceptible to being damaged: (1) during piling works; (2) during pile trimming works; (3) by follow on trades unwittingly digging, cutting or burning through geothermal loops. Most damage is generally caused during the pile trimming phase by follow on trades. It is essential that prior to and after each key stage of works where loops are to be incorporated within the works, loops are flush tested with water and a basic pressure test is undertaken to verify installation, as shown in Figure 14. Pre-concrete and post concrete testing should include both flush test and pressure testing to verify installed loops at all stages of work (i.e., piling, pile trimming).

Once thermo-piles start to be linked together within pile caps it is recommended that loops are filled with water and 6 bar pressure is maintained within the loops, as shown in Figure 15(a). If loops are damaged during follow on works, water will leak out and the pressure will fall. The headering of the geothermal loops within the floor slab should be routed with appropriate pipe connections to ensure a balanced flow of heat exchange fluid through all of the loops, and should be arranged to avoid damage from exposure, as shown in Figure 15(b) and 15(c). Pile caps, floor slabs, or grade beams should not be concreted until geothermal loop circuits have been pressure tested and pressure is maintained for at least 24 hours. After installation of the system, the heat exchange loops should be arranged in a manifold, with appropriate valves to balance the flow of heat exchange fluid through each thermo-pile.

7. Final Comments

This document has set out recommended best practice for the installation of geothermal loops within foundations and is based upon considerable experience gained over the past 10 years in the UK. Whilst there are several important considerations to be taken when considering thermo-piles, what is of paramount importance is the early stage coordination with all parties that will encounter and incorporate loops with their works. Through early stage coordination, incorporating geothermal loops within foundations and the construction process should be able to be undertaken without additional program implications and minimal costs. This, coupled with the fact that there are additional costs and implications associated with other ground-source solutions, using thermo-piles provides an ideal solution for a renewable energy source.

8. Acknowledgement

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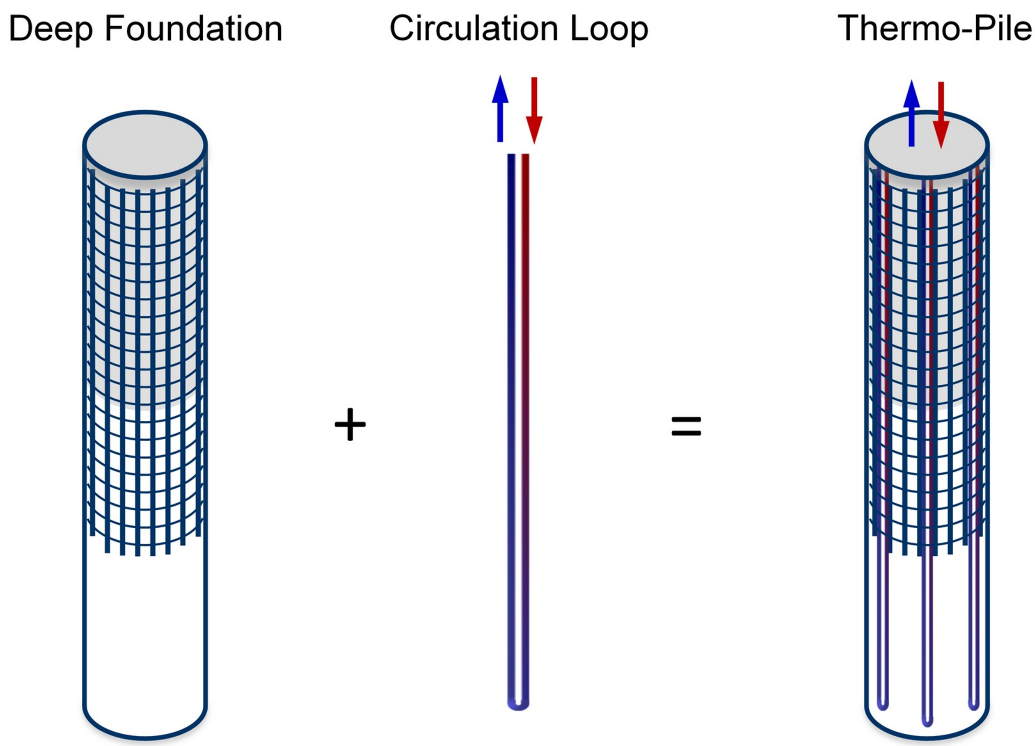
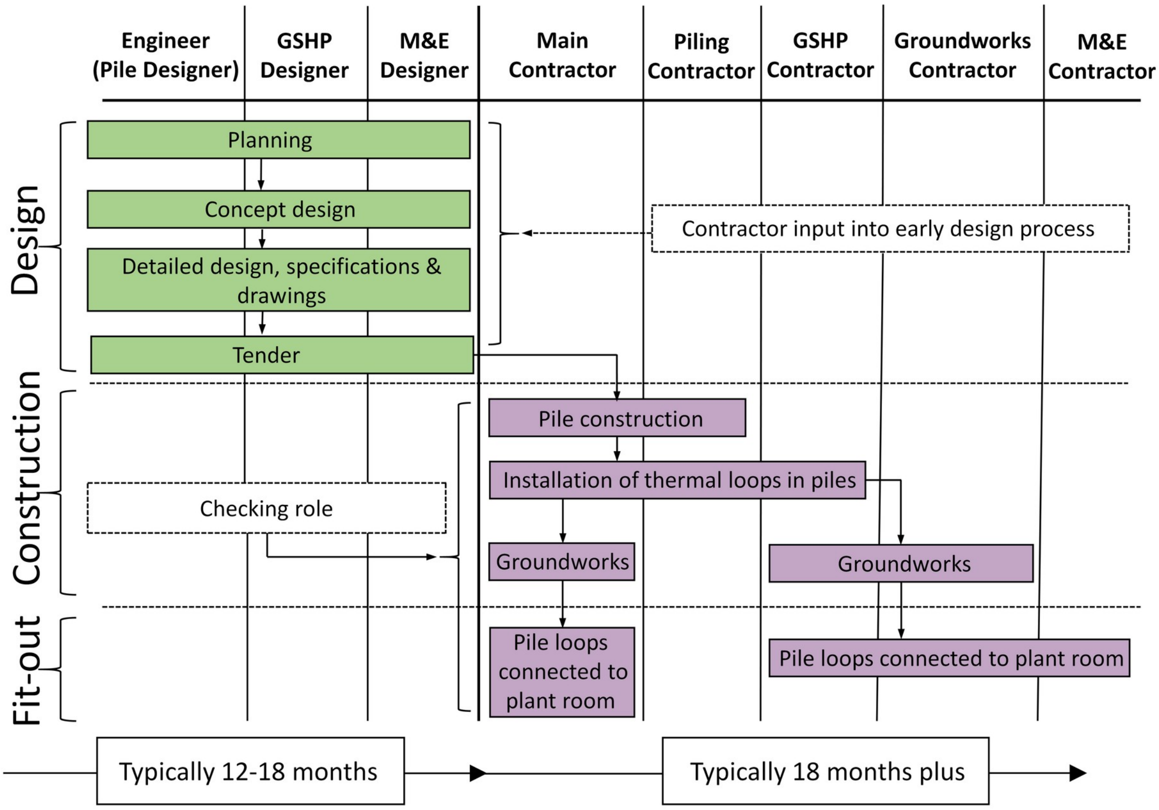


Figure 1: Thermo-pile with geothermal loops installed through the full depth of the pile to maximize heat exchange capabilities



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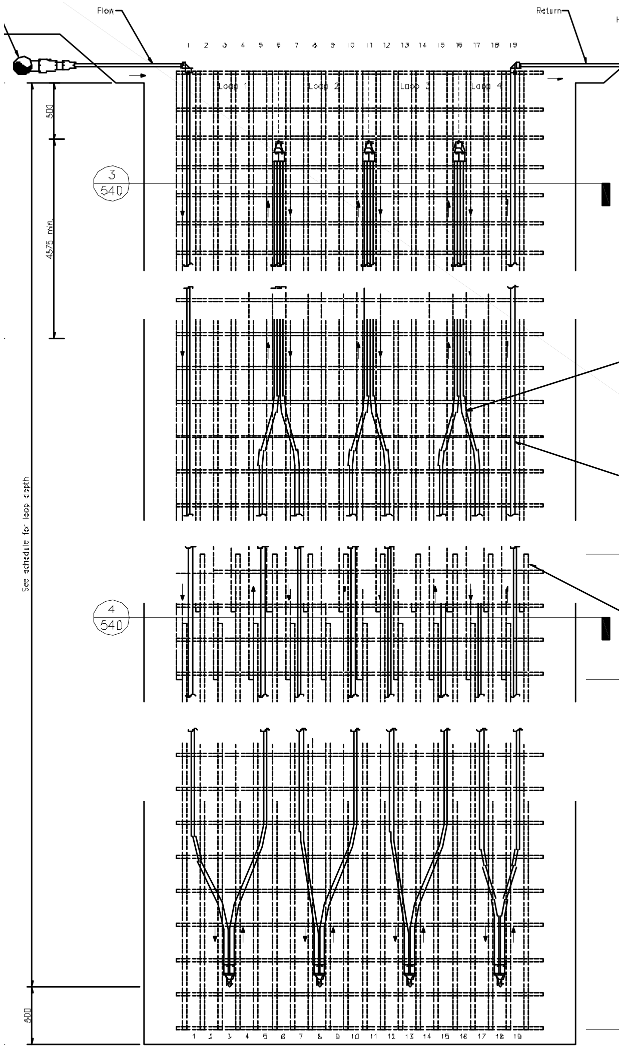

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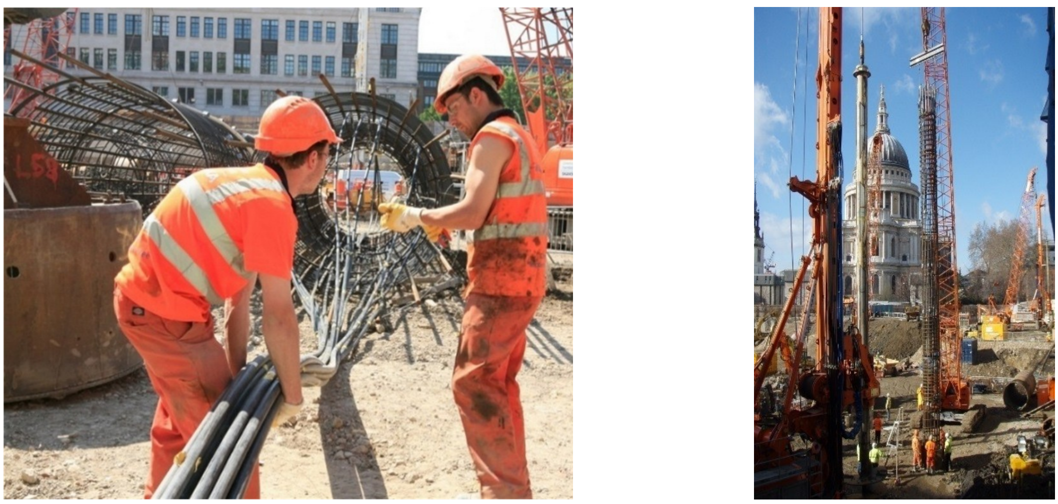

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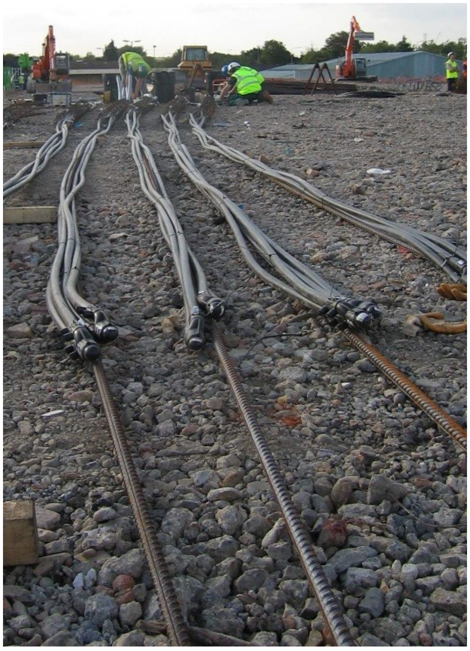

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