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Directors' research and development activities

Redefining the way sustainable construction is delivered

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Background

The deep foundations industry has largely remained unchanged since the 1960s when CFA (continuous flight auger) piling was established, with much of the plant and construction methodologies remaining the same. Therefore, piled foundations have largely continued to be designed and constructed using traditional codes and standards, which use very high factors of safety, with little regard for optimizing in-life efficiency or end-of-life reuse.

After existing developments have been demolished there is little motivation to reuse existing piled foundations as their load bearing capacity and structural integrity cannot be verified. Therefore, piling contractors are increasingly spending more resources on coring through existing piles, only to then replace these with larger diameter or deeper piles. This is incredibly resource intensive and a very unsustainable way of delivering construction projects.

Many of the earlier structures were demolished, only to be redeveloped in 20–30-year lifecycles. During redevelopment, a superstructure is typically demolished which results in an unloading of the existing piles. The removal of the vertical stress triggers the process of basal heave causing the ground, and all its inclusions, to move upwards. This heave can result in a differential displacement along the lengths of the piled foundations and therefore cause cracking along the length of a pile, rendering piles unusable. This is one of the many reasons that piled foundations are not typically reused.

Additional challenges involved with pile reuse occur as a result of the piles being unavailable for inspection or survey until the structure has been demolished. At this stage the majority of the design is complete and relying on accurate historic as-built data is considered high risk. Therefore, it is easier to disregard any existing foundations at concept stage, and allow the piling contractor time to remove any obstructions. Whilst this presents a low risk approach it is very unsustainable as the ground in cities is becoming increasingly congested with foundations.

More foundation appraisal options must be developed to enable the foundations industry to move away from the linear economy model, towards a circular model which promotes and supports the reuse of existing foundations, as shown in **Fig. 1**.

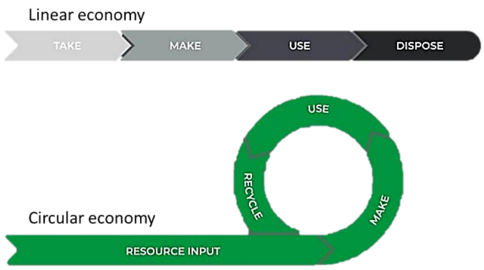


Fig. 1. Linear vs. circular economy model

HIPER® Pile

The HIPER® Pile is a new foundation technology that was developed by Keltbray, a specialist engineering and construction company based in the UK. The product combines a range of innovations specifically designed to minimize carbon emissions during construction, occupancy and at end of service.

The HIPER Pile stands for Hollow, Impression, Precast, Energy generating, and Reusable Pile. Each of the innovative strands were developed in collaboration with partners including, City, University of London, G-Core energy. Significant efforts were required to develop the technology to enable the full potential to be demonstrated on the development of a new accommodation block for HS2 Euston Station.

The benefit of this foundation solution is that it enables access to the pile during occupancy as the load is transferred directly into the annulus, see **Fig. 2**. Access permits an assessment of the pile to measure the length, as-built the coordinates, take core samples, and so on, to confirm whether the pile can be successfully reused. As this evaluation can be completed during occupancy it allows the design to progress with the relevant information to mitigate any risk of changes as the project proceeds.

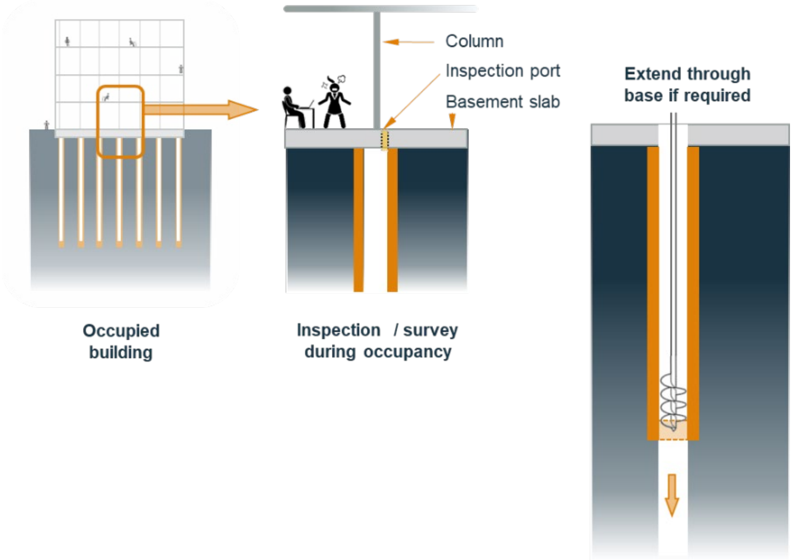
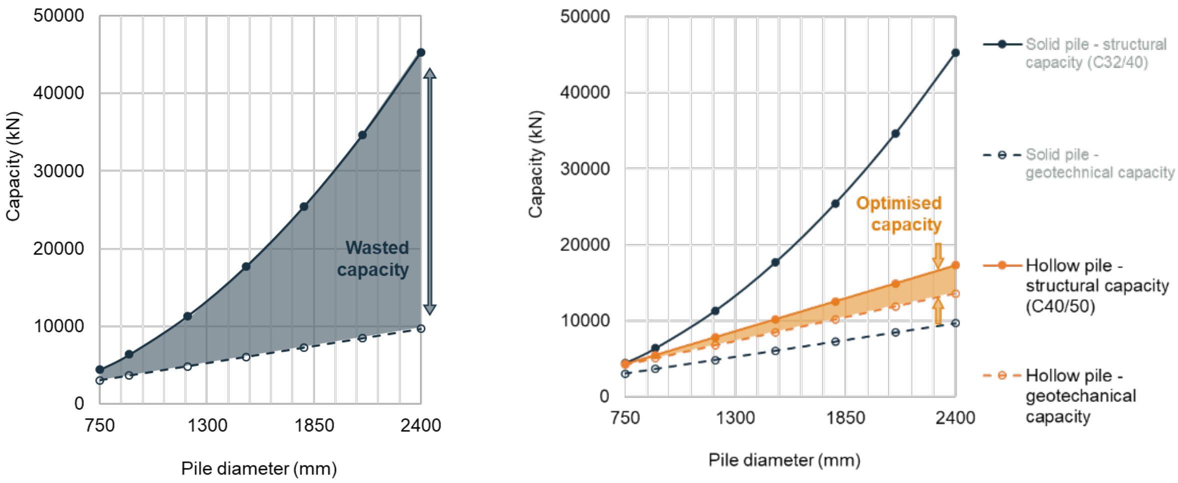


Fig. 2. Inspection of hollow piles during occupancy

Furthermore, there are environmental challenges associated with constructing increasingly large and deep piles, such as inefficiencies between the structural and geotechnical capacities of the pile. For example, a 2.4m large diameter pile constructed with 40N concrete has a capacity of 4.5MN. However, in typical ground conditions in London, the geotechnical capacity of the pile may be limited to 2MN. Therefore, there is a significant volume of concrete that is redundant, see **Fig. 3**.

However, the benefits of the HIPER pile allow the designers to optimize the pile efficiencies and match the structural capacity closer to the geotechnical capacity. Enhancing the shaft capacity of the pile also positively impacts the geotechnical capacity, further closing the gap between the structural and geotechnical capacity.



(a) (b)

Fig. 3. Inefficiencies between structural and geotechnical capacity based on pile diameters for (a) solid piles and (b) hollow piles

HS2 HIPER Pile case study

This technology was deployed on the first live contract which called for the installation of forty HIPER Piles beneath the new welfare units for the HS2 Euston Station development. The client was keen to use this project as an opportunity to innovate and understand the benefits of the technology, with a view to adopting this at scale across other stations along the route.

The piles were bored with a 900mm diameter auger designed with 500mm diameter voids. The piles were impressed with a bespoke tool that enhances the skin friction before a void forming liner was installed in the center of the bore. The concrete is placed to the base and the annulus before the pile is temporarily capped. To support the thermal energy system the voids are filled with water during the platform excavation and geothermal u-loops are plunged into the piles (see **Fig. 4**).

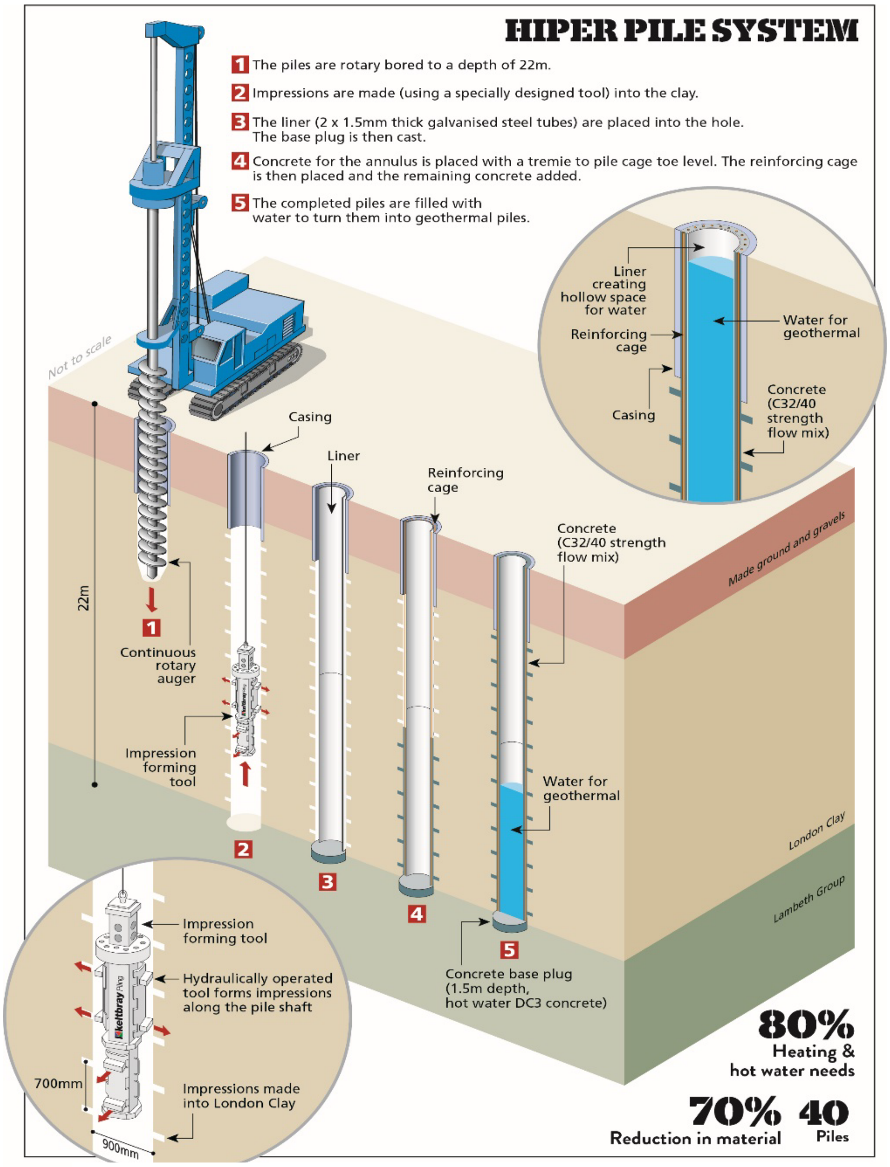


Fig. 4. HIPER Pile construction (NCE, 2022)

A previous study (Panchal et. al., 2019) was carried out to compare the load bearing capacity of a solid stiff pile against a lower stiffness pile modelling a hollow pile. **Fig. 5** shows the improved capacity of the lower stiffness hollow pile compared with a traditional solid stiff pile. This is owing to the pile displacing under load which in term mobilizes more of the soil strength.

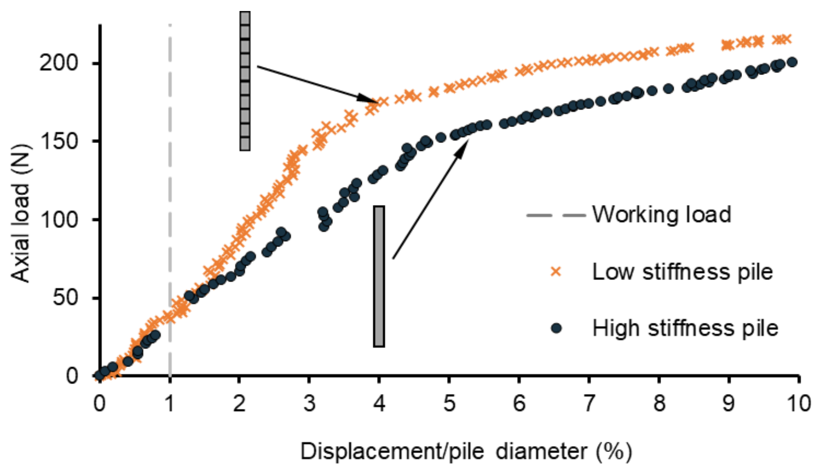
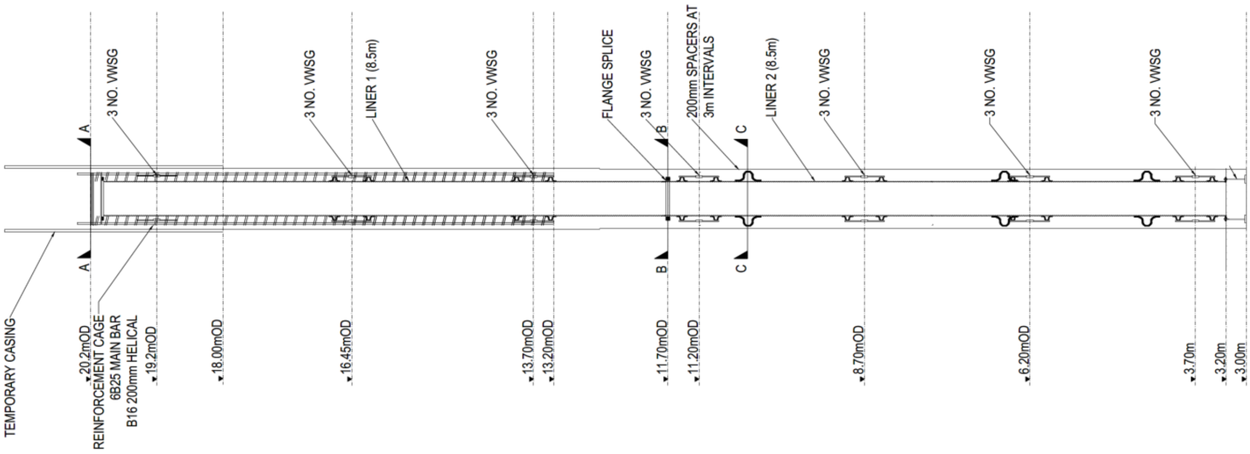
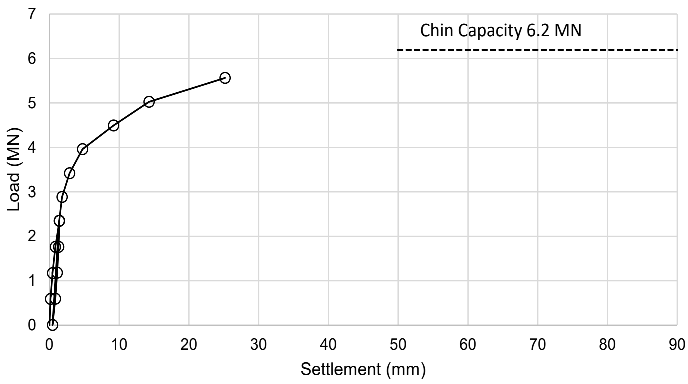


Fig. 5. Hollow pile increase capacity (Panchal et al., 2019)

A further full scale instrumented preliminary test pile was installed and tested at the HS2 Euston site. This was constructed as a hollow, impression pile cast with in-situ concrete technology. The arrangement and construction phase are illustrated in **Fig. 6(a) and (b)**. The pile was installed with seven levels of strain gauges installed along the length of the pile. The safe working load (SWL) of the pile was 2.1MN and loaded up to the capacity of the test frame (5.6MN), however the pile had still not reached ultimate capacity. Using Chin's method (1970) the estimated pile capacity was 6.2MN as shown in Fig. 6(b). The improved capacity of this hollow test pile demonstrates the benefits of adopting a new construction method over traditional methods.



(a)



(b) (c)

Fig. 6. Preliminary test pile (a) details at HS2 Euston, (b) installation of void former for the test pile and (c) interpolated load-settlement curve

Conclusions

There is an urgent need to adapt current design and construction practices to support sustainable development. The HIPER Pile is a new technology that has been through a rigorous R&D programme, taking the idea from concept to fruition with a full scale project delivered an entirely HIPER pile foundation scheme. The product combines a range of technologies to reduce the volume of material used and encourage foundation reuse through accessible data acquisition; thereby limited embodied carbon.

A case study was outlined and by adopting HIPER piles on the HS2 station site in London, a total of 280m^3 of concrete was eliminated, and each of the piles were shortened by an average of 4m by enhancing the shaft with impressions. This corresponds to material and vehicle movement savings of over 40%. The hollow piles provided ground source energy; if a conventional foundation scheme was adopted, would have required either full length reinforcement cages which would use 70% more reinforcement than was required on this scheme, or the installation of more than 60no boreholes drilled to depths in excess of 100m. All of these contributing factors present carbon savings in excess of 35% compared with a traditional piled scheme.

References

Chin, F.K., 1970. Estimation of the ultimate load of piles from tests not carried to failure. Proceedings of the Second Southeast Asian Conference on Soil Engineering, pp83-91.

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