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Short communication

A novel joint for driven concrete geothermal energy pile foundations

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ABSTRACT

Geothermal energy pile foundations are among the most common types of energy geostructures which provide both structural support and can be used as a source with ground source heat pumps for heating and cooling buildings. Energy piles can be categorized into cast-in-place and precast piles. Driven precast concrete energy piles can be installed up to the bedrock level, with higher quality, lower cost, and faster installation process, compared to cast-in-place energy piles. Precast concrete driven energy pile foundations have not been commonly utilised due to existing problems with a suitable type of joint that could connect precast segments and allow continuity of heat exchanging pipes. An innovative and novel steel driven energy pile (DEP) joint is presented in this paper which can provide structural integrity between the segments and leak-proof coupling between the heat exchanging pipes. Both sizes of DEP joints passed 1000 impact blows of 28 MPa, they remained undamaged during the bending tests with a flexural stiffness of 3500 kN.m^2, and 7720 kN.m^2 for the 267 mm and 350 mm joints, respectively. Additionally, the pipes used in the prototype joints and piles indicated no leakage or pressure drop in the hydraulic pressure tests subjected to 690 kPa pressure.

1. Introduction

Geothermal energy pile foundations are among the most popular ground heat exchanging (HE) systems, which are mainly designed for providing structural support, and additionally can be used for heating and cooling buildings [1,2,3]. Energy pile foundations can be categorized based on their method of construction into (a) cast-in-place piles, (b) precast piles, and (c) continuous flight auger (CFA) piles [4]. Energy piles can be also categorized based on their materials into (a) concrete, (b) steel, and (c) composite piles. Composite piles are steel piles filled with concrete or other filling materials.

Cast-in-place concrete energy pile foundations are the most common type of energy piles used in the construction industry and they have been well-investigated in the past two decades [5]. Another type of concrete energy pile which can be used under the buildings is precast concrete driven energy piles, which are cast at a concrete factory with high quality and under a controlled curing condition, and in massive quantities [6]. Their installation has a higher speed without any drilling, hence, having a lower cost compared to borehole heat exchangers and cast-in-place piles. This results in the shortest payback period compared to other ground-source heat exchangers [7].

The main challenge of driven precast concrete energy piles is that they should be built in segments of 12–15 m, due to the existing limitations in transportation, i.e. vehicles and road limitations and regulations [4]. As a result, when longer energy piles are required, several precast concrete energy pile segments should be connected using a joint to make a longer pile as shown in Fig. 1.

Single-segment precast concrete energy pile foundations were investigated by Alberdi-Pagola [8,9] and were used in Denmark [10]. The single-segment precast piles can only be used when the required pile length is small (12–15 m), and the bedrock is close to the ground surface. Thermo-mechanical behaviour of a similar type of quadratic-shaped precast concrete energy piles with two segments was investigated in Spain [11]. The piles had a large cylindrical central conduit through their structure and joints, where the HE loops were inserted through them into the pile and the remaining gap was filled with cement grout [12,13,14]. Hollow cylindrical concrete energy piles are also another type investigated previously [15,16]. Putting the HE loops in the hollow space inside of such piles provides a limited distance between the inlet and outlet pipes reducing the thermal performance of the HE loops [17]. The hollow space also reduces the structural capacity of the pile as the cross-sectional area of the pile is reduced and the hollow space is filled with cement grout which does not have the same strength as concrete.

The main goal of the present paper is to present a recently patented and tested steel driven energy pile (DEP) joint [18], which can be used

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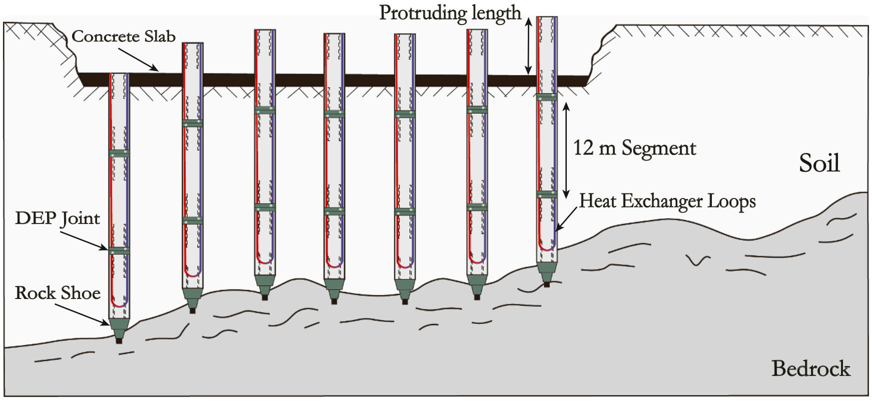

Fig. 1. Schematic illustration of end-bearing driven energy piles (modified from [4]).

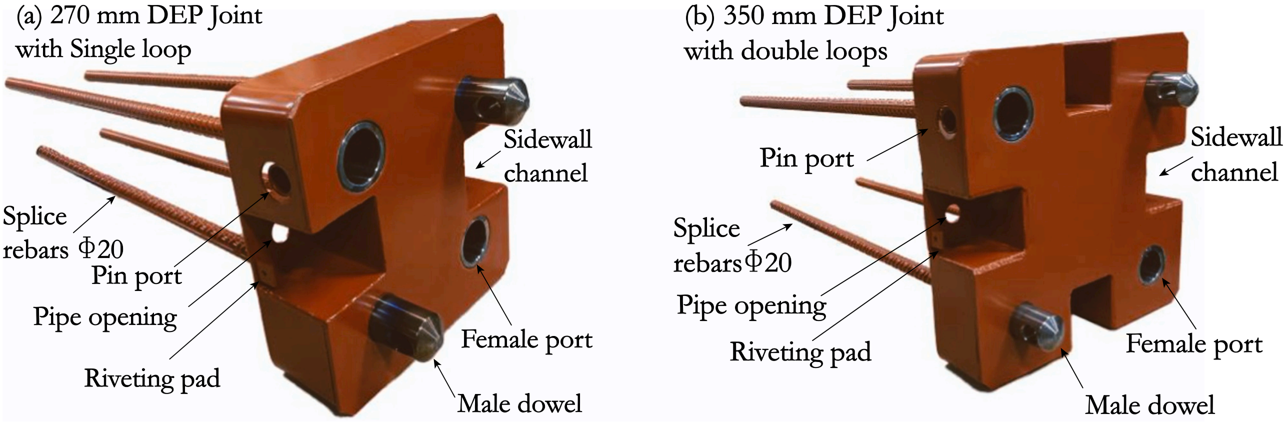

Fig. 2. DEP joint details.

for connecting driven precast concrete energy piles. Then the structural integrity tests, including impact and bending tests performed on DEP joints are briefly presented and discussed. In addition to structural integrity tests, the hydraulic pressure tests are also presented.

2. Driven energy pile joint (DEP joint)

Conventionally, steel joints connect precast concrete energy pile segments, which are either welded together, which is expensive and time-consuming, or steel pins are used which can instantly connect and lock the pile joints together. The conventional types of steel joints available in the market do not provide the possibility and space for connecting the HE loops. Hence, a new generation of joints was developed in two sizes, i.e., 270 mm and 350 mm, to accommodate the HE loops inside the DEP joint, as illustrated in Fig. 2. The pipe with sizes of 20 or 25 mm can be embedded inside the pile during casting and coupled through the sidewall channels using fusion welded couplings when installing the piles in a field. The male and female dowels will be locked together using steel pins which are inserted from pin ports.

3. Structural integrity tests

Any type of joint used in the piling industry shall pass structural integrity tests, i.e. impact and bending tests, according to the BS EN 12794 standard [19]. In each joint size, three piles consisting of two segments which were connected using the proposed DEP joint underwent impact and subsequent bending tests. In the following section, the details of the test procedures are explained, and the results are presented.

3.1. Impact tests

The BS EN 12794 standard classifies steel joints into four classes based on their structural performance and strength. The DEP joints presented in this study were “class A” joints, i.e., the highest class of strength, hence they were tested for a minimum of 1000 impact blows imposing a stress level of 28 MPa.

3.1.1. Preparation of the HE pipes before connection

After casting the pile segments at a concrete factory, they were transported to the test site facility at Leimet OY in Finland for the impact tests. Initially, the protruding length of the HE pipes (Fig. 3a) was cut to the desired length, and the outer surface of the pipes was peeled to remove the oxidised layer of plastic and clean it before connecting the pipes with fusion couplings. Then the couplings were mounted on the pipe as shown in Fig. 3b.

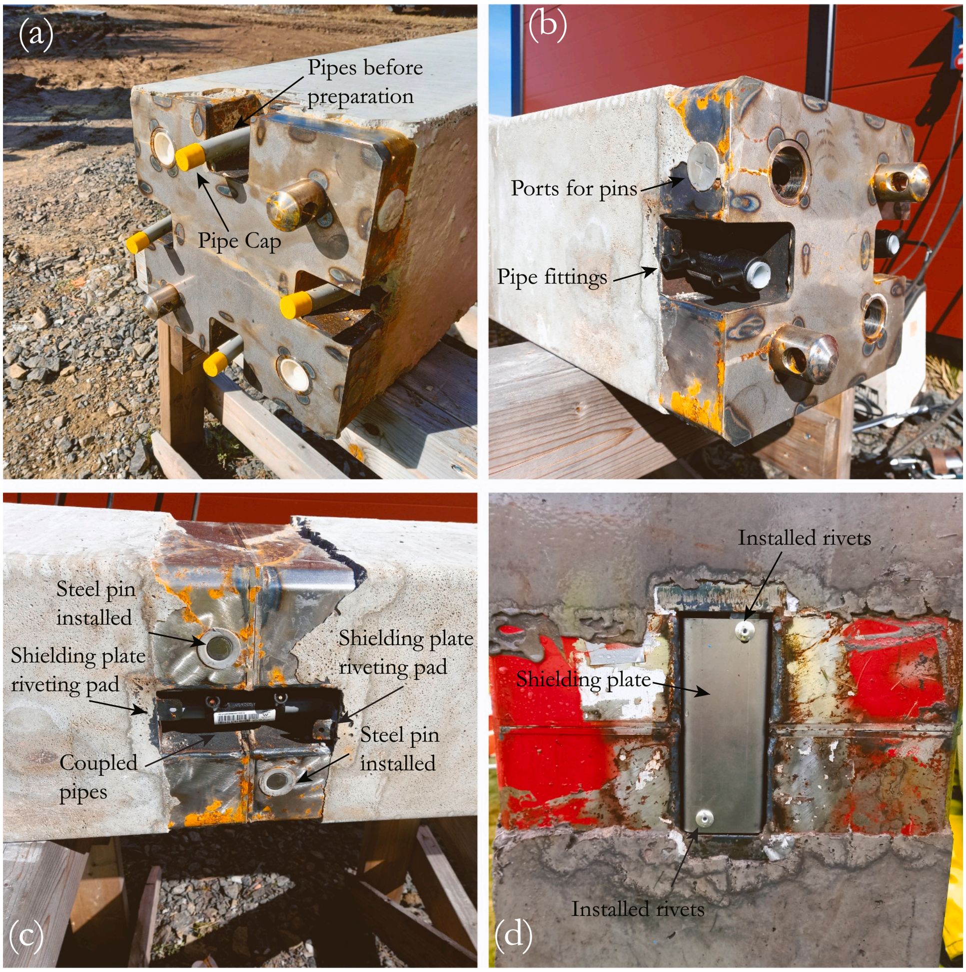

Fig. 3. The procedure of connecting the pile segments and pipes using DEP joints.

Fig. 4. Impact test setup.

Table 1
Measured stress levels and settlements during impact and blow tests.

Test Specimen	Average CSX [MPa]	Average CSI [MPa]	Blows	Settlement for500/1000 blows [mm]
B270–2 (P6)	32.1	39.2	≥ 1000	8 / 9
B270–3 (P5)	29.9	40.0	≥ 1000	5 / 7
B270–4 (P4)	30.5	42.6	≥ 1000	6 / 8
B350–1 (P12)	29.3	32.9	≥ 1000	6 / 9
B350–2 (P9)	28.8	30.7	≥ 1000	6 / 8
B350–3 (P8)	29.5	35.3	≥ 1000	8 / 9

Table 2
Bending capacity results for the test piles.

Test Specimen	Max. external load [kN]	Max. moment [kN.m]	Yielding moment [kN.m]	Calculated Max. moment [kN.m]
B270–2 (P6)	136	69.9	64	70
B270–3 (P5)	140	71.1	65	70
B270–4 (P4)	137	70.5	65	70
B350–1 (P12)	180	109.8	96	103
B350–2 (P9)	180	109.7	96	103
B350–3 (P8)	180	109.8	97	103

3.1.2. *Connecting the pile segments*

After preparing the pipes, the joints can be structurally connected. Each pile segment has a joint part which is composed of two male dowels and two female ports. At the interface between the two pile segments, the joints are assembled and then locked using steel pins as shown in Fig. 3c.

3.1.3. *Coupling the pipes*

After the joints are structurally connected, the pipe couplings can easily slide over the already prepared pipes inside the sidewall channels and be placed in their correct position in a way that the centre of the pipe coupling is exactly located at the centre of the sidewall. Then the pipe will be coupled using a regular fusion welding tool which provides a perfect coupling between the pipes of the two energy pile segments as shown in Fig. 3c. The pipes and fittings used in this study were Plasson Smartfuse electrofusion fittings and RauGeo PE-Xa pipes which can take 16 and 15 bars of pressure at 20 °C, respectively. The sidewall channels can finally be covered with a steel shielding plate, riveted to the joints, which protects the pipes from harsh frictions in the ground as shown in Fig. 3d.

3.1.4. *Impact test results*

Three energy piles in each size were tested for 1000 impact blows. According to the EN 12794 standard, the pile tip should be located at a strong bedrock in a way that during the 1000 blows, the pile joint remains over the ground surface so that it can be eye-inspected. For this purpose, the Leimet test facility has a large steel box with thick plates which prevent the piles from penetrating into the ground (Fig. 4a).

A pile driving analyser (PDA) system was used to monitor the stress level induced by each impact. PDA measures the strain and compression wave imposed by each blow and then converts them to the compression/tensile stresses (Fig. 4). It is important to embed the HE loops in the concrete in suitable places, i.e., in the corners or at the centre of each side wall, so that the drilled holes for PDA measurement sensors do not damage the HE loops. The results of the impact tests are presented in Table 1. CSX is the maximum stress averaged over the cross-section, and CSI is the maximum compressive stress at an individual transducer, which both have an average above 28 MPa. During the impact tests only the blows that induce a stress level of 28 MPa were counted, hence the total number of impacts was more than 1000 blows. The vertical displacement of the pile after every 500 blows were measured and reported, which were less than 10 mm and could be due to the displacement of the test box platform or the rock shoe at the tip of the pile.

3.2. *Bending test procedure and results*

After the impact tests, the piles were cut to specific lengths of 4000 mm for the 350 mm piles and 3500 mm for the 270 mm piles.

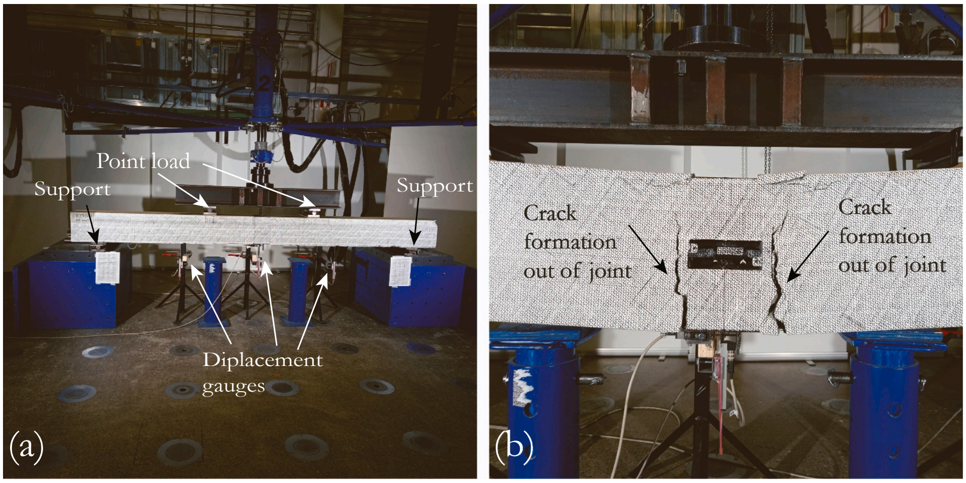

Fig. 5. The bending test setup, (a) loading, (b) failure outside the joint.

Table 3
Pressure test results.

Test	Date	Confirmed 100% water?	Initial Expansion phase, 3 h, Maintain 100 psi							Test Phase 100 psi		Final Δ psi	% of test phase psi	Pass (P) Fail (F)
			30 min 100 psi	60 min 100 psi	90 min 100 psi	120 min 100 psi	150 min 100 psi	180 min 100 psi	Gross Makeup psi	30 min psi	60 min psi			
P1 270	08.05.2023	Yes	95	98	98	99	100	100	10	100	99	1	1%	P
P2 270	08.05.2023	Yes	98	97	98	100	100	99	8	100	100	0	0%	P
P3 270	08.05.2023	Yes	97	98	99	100	100	100	6	100	100	0	0%	P
P7 350	09.05.2023	Yes	90	98	100	100	99	100	13	98	100	2	2%	P
P8 350	09.05.2023	Yes	95	99	100	99	100	100	7	99	100	1	1%	P
P9 350	09.05.2023	Yes	98	99	100	99	99	100	5	100	100	0	0%	P

Then these piles were tested at the structural laboratory at Tampere University to measure their bending capacity and check if they remain undamaged after the tests by monitoring the deformations of the joint (Fig. 5). The concrete piles were designed in a way that the concrete structure has a higher design than the joint, hence the flexural failure was expected to happen at the rebars of the joint. During all of the tests, the failure occurred exactly outside the joint in the concrete rebars, while the joint remained undamaged and undistorted (Fig. 5b). The maximum moment is measured from the peak of the moment-deflection diagram, and the yielding moment is at the point where the initial linear behavior finishes in the moment-deflection diagram. The results of the bending capacity of the piles tested in this study are summarized in Table 2.

4. Hydraulic pressure tests

After the impact testing was finished and before starting the bending tests, the pipes were pressurized up to 100 psi according to ASTM F2164 – 21 standard [20]. These tests have two phases: (a) the initial expansion phase, which lasts for 3 h, and (b) the test phase, which lasts for 90 min. In the initial expansion phase, the pipes were filled completely with water and pressurized to 100 psi and checked every 30 min, and make-up pressure is applied to maintain the 100-psi pressure. Then in the main test phase, the total pressure drop should not be more than 5% otherwise the test is considered failed.

In the present study pressure tests were performed on three piles of 270 mm and three of 350 mm size. All of the pressure tests were considered “passed” by the standard, as no apparent leakage was observed and the pressure loss in the system was less than 5% of the initial 100 psi as presented in Table 3. The details of the pressure test setup are shown in Fig. 6. The minor pressure drops in the initial expansion phase were mainly due to the effect of pipe expansion and minor air bubbles that dissolved into the water, which was normal.

5. Conclusions

An innovative steel joint for precast concrete driven energy pile foundations known as DEP Joint is presented, with structural and hydraulic pressure test results. Using DEP joints, the loops are installed inside the structure of the pile, before pouring concrete into the formwork at the concrete factory. DEP joints allow driving long segmental energy piles up to the deep bedrock levels. Both sizes of DEP joints passed 1000 impact blows of 28 MPa, they remained undamaged during the bending tests with an average flexural stiffness of 3500 kN.m^2, and 7720 kN.m^2 for the 267 mm and 350 mm joints, respectively. Additionally, no leakage or pressure drop was observed in the hydraulic pressure tests subjected to 690 kPa pressure.

CRediT authorship contribution statement

Sadeghi Habibollah: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Singh Rao Martand:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

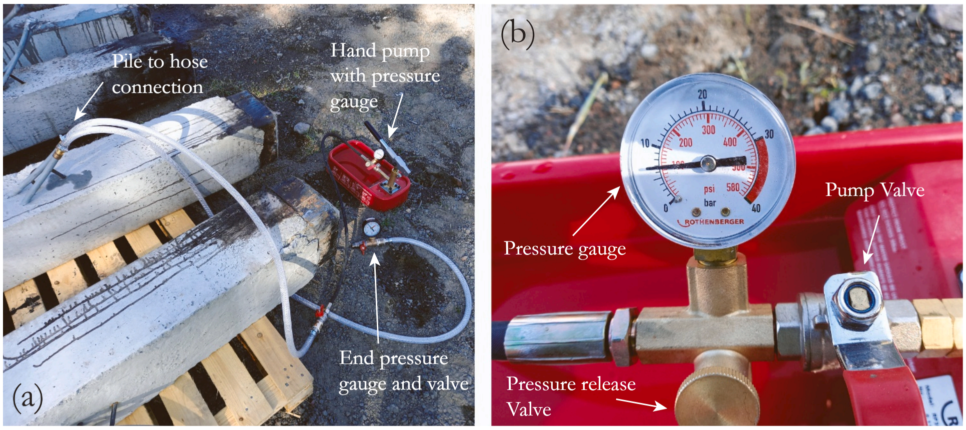

Fig. 6. Hydraulic pressure test setup.

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