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Invention Article

A steel joint for driven precast concrete geothermal energy pile foundations

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ABSTRACT

This invention describes a steel joint used for connecting two precast concrete driven energy pile (DEP) segments which is known as DEP joint. Precast concrete DEPs are cast in segments with a maximum length of 12 m at a concrete factory. DEPs are typically driven into the ground until bedrock; hence, in places where the bedrock is deeper than 12 m, two or more segments must be connected using a joint to produce longer energy piles. DEPs have not been frequently used because no suitable joint existed that could maintain structural integrity and provide leak-proof coupling between the pipes at the joint interface. The present invention addresses this problem by designing a steel joint that can meet the structural and hydraulic requirements of a suitable steel joint for DEPs. Each quadratic concrete energy pile segment is prefabricated in a concrete factory, where the heat transfer pipes are embedded inside the steel cage of each segment. The steel DEP joint is installed at one or both ends of each concrete segment, and has two or four sidewall channels, depending upon its size. Heat transfer pipes are coupled between every two segments, inside the sidewall channels, while the energy piles are installed at a construction site. The sidewall channels are protected using steel shielding plates that are riveted to the joint so that the pipes and the coupling inside the sidewall channels are protected against harsh frictions during the installation of the DEPs in the ground. The steel joint facilitates the installation of longer precast concrete energy piles up to the bedrock depth, especially in sites where the bedrock is deeper than a single segment length. The main advantages of precast concrete energy piles compared to cast-in-place piles are that they enable better quality control and quality assurance, as well as being easier, faster, and cheaper to install. The invented DEP joint has passed structural integrity tests as required according to the BS EN 12794 standard, and also passed hydraulic pressure tests according to the ASTM F2164 – 21; hence, it is certified to be used in construction projects. We are now looking for potential licensees to start manufacturing the joints and using them in the energy pile industry.

Specifications table

Subject code	1909-Geotechnical Engineering and Engineering Geology, Physical Sciences 2105-Renewable Energy, Sustainability and the Environment, Physical Sciences
Specific subject area	Steel joint for prefabricated geothermal energy piles made of concrete or reinforced concrete or made of steel and concrete
Industry code	E Fixed constructions
Details of inventors	Habibollah Sadeghi, PhD candidate, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Email: habibollah.sadeghi@ntnu.no Rao Martand Singh, Professor, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), Email: rao.m.singh@ntnu.no

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Dates of invention	Conception: November 2021 Disclosure: 19 May 2023
Patent details	Date patent granted: Pending Patent owner: Norwegian University of Science and Technology (NTNU); NTNU Technology Transfer AS Patent attorney or agent: Conor McLaughlin, Dehns Contact for service: Lodve Berre, lodve.berre@ntnu.no Link to patent: https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2023084125&_cid=P11-LI02CC-95824-1
Intended use	We intend to commercialise the invention through licensing.
Related research article	H. Sadeghi, R.M. Singh, "A novel joint for driven concrete geothermal energy pile foundations." Engineering Structures 301 (2024): 117270. https://doi.org/10.1016/j.engstruct.2023.117270 H. Sadeghi, R.M. Singh, Casting and installation of segmental precast quadratic concrete driven geothermal energy piles.

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1. Value of the invention

- The use of DEP joints facilitates using precast concrete driven energy piles (DEP) as a source of geothermal energy for ground source heat pumps (used for both heating and cooling). DEPs can be installed at any location and any bedrock depth; hence enabling the use of geothermal energy in conditions where this was previously not economically feasible due to operational conditions. DEP can be installed in places where cast-in-place piles are not an option due to shallow groundwater table or sites with soft deposits where casings are required for drilling.
- Precast concrete energy piles that are constructed using DEP joints, can benefit various stakeholders, such as building owners/developers, construction companies specially piling companies, joint manufacturing companies, environmental organizations, government and regulatory bodies, urban planners and architects, energy suppliers and utility companies, residents, and tenants.
- Driven energy piles can be used both for exchanging/storing heat with/in the ground which helps sustainable urban development. DEPs can be also integrated into the district heating and cooling networks, which provide a more resilient, and reliable energy for heating and cooling buildings. DEPs can be also further integrated into photovoltaic-thermal (PVT) solar panels which can also harvest heat from the panels, and increase the electricity production efficiency of the solar panels by reducing their temperature [15].
- Buildings that utilize energy piles with ground source heat pumps have a higher market value [26] as they can benefit from energy markings of A or B due to the utilization of renewable energy. Building with energy marking of A and B can receive governmental support and incentives such as green loans [7]. Additionally, residents of buildings with such a system will benefit from reduced energy bills, due to the increased building energy efficiency [3,13].

2. Invention description

The DEP joint creates a fast and robust coupling between prefabricated concrete energy pile segments and their heat transfer tubes without compromising on the structural capacity. DEP joint paves the way for harnessing geothermal energy from the foundations of a building, covering the base heating/cooling demand of various types of buildings. DEP joints have been developed and tested in two sizes of 270 mm (with two sidewall channels for one loop), and 350 mm (with four sidewall channels for two loops) [23]. Joints with larger sizes such as 550-mm, can be manufactured using the same details presented in this work. The 3D details of single 270-mm and 350-mm DEP joints are illustrated in Figs. 1, and 2.

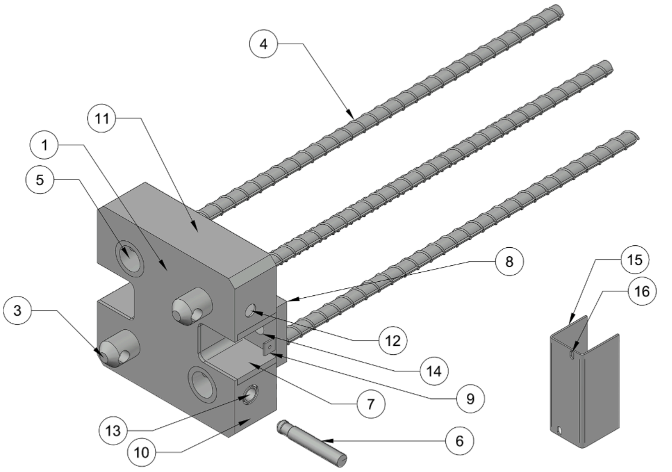

Fig. 1. Isometric view of 270-mm NTNU DEP joint.

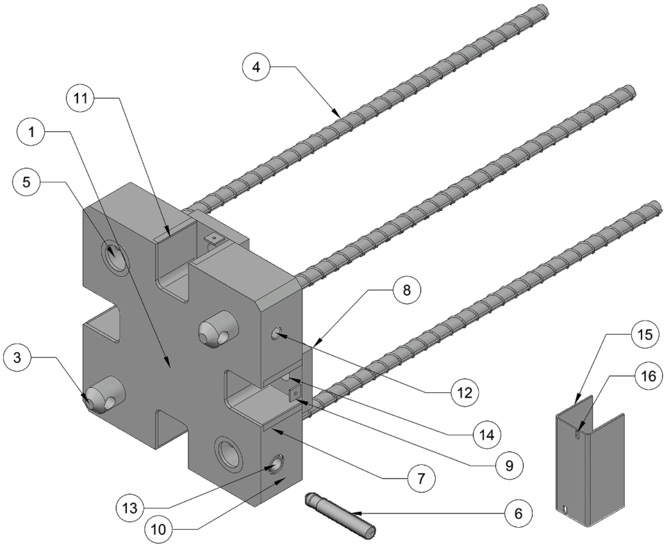

Fig. 2. Isometric view of 350-mm DEP joint.

The main body of the joint consists of a bottom plate (1) welded to collar plates (10)(11). The joint has four rebars (4), which are welded to the male locking dowel (3), or the female Locking block (2). Each joint has one or two air holes (12), which facilitate the exit of air bubbles during the vibration of fresh concrete at the concrete factory. Each sidewall channel consists of a wall plate (7) and the top plate (8), which has a central hole (14), where the heat transfer loops pass through. The heat transfer pipes are coupled in the sidewall channels, using commercially available fusion welding couplers. After assembling the two segments of energy piles, pins are installed inside the locking block through the locking block pin holes (13). The assembled joints are also shown in Figs. 3, and 4, and the dimensional details of 270-mm and 350-mm joints are shown in Figs. 5 and 6.

At the end, a shielding plate (15) covers each sidewall channel and will be fixed in place using rivets. Shielding plates have two bean-shaped rivet holes (16), where the rivets are inserted, tying the shielding plates to the riveting plate (9) inside the sidewall channel. The role of the shielding plate is to protect the heat transfer pipes and coupling at the joint interface from the harsh side frictions between the joint and the ground during the pile installation. The details of the shielding plate are presented in Fig. 7.

Both sizes of DEP joints have already passed the structural integrity tests, including impact and flexural tests, according to the BS EN 12,794 standard [5]. The two sizes of DEP joints are compared in Table 1. The piles also passed the leakage tests according to ASTM F2164 – 21 [2] after the impact tests. The results of the structural integrity tests, and hydraulic pressure tests, including the flexural stiffness of the joints are presented in detail elsewhere [21,18]. Any qualified steel production company can produce DEP joints. It is essential to manufacture the joints with high quality, as the joints must connect two segments vertically, and minor deviations due to poor quality might cause extra bending moments on the joints. The casting procedure of driven energy piles using DEP joints is also straightforward, and any concrete factory, that is

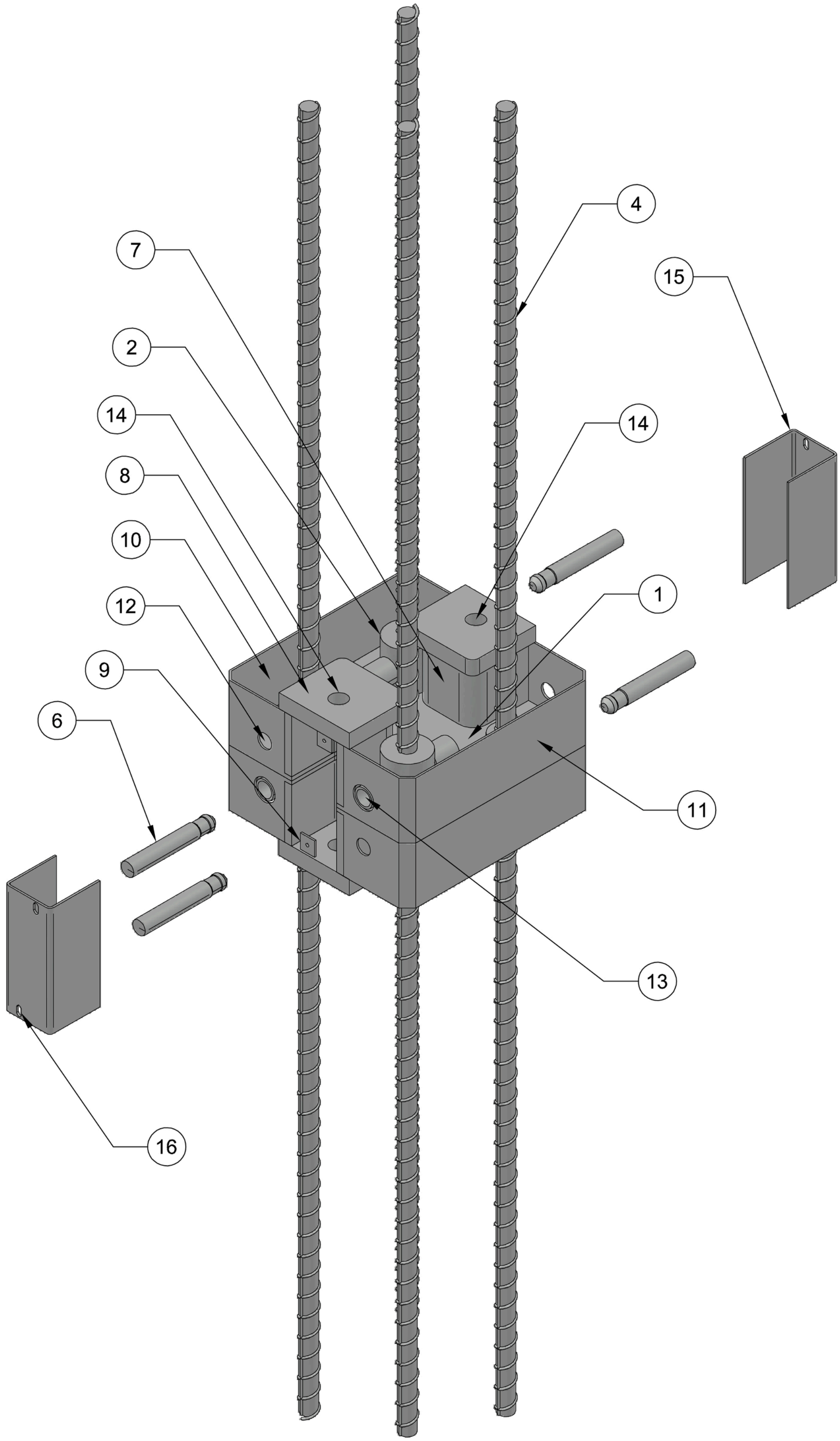

Fig. 3. Isometric view of assembled 270-mm DEP joint.

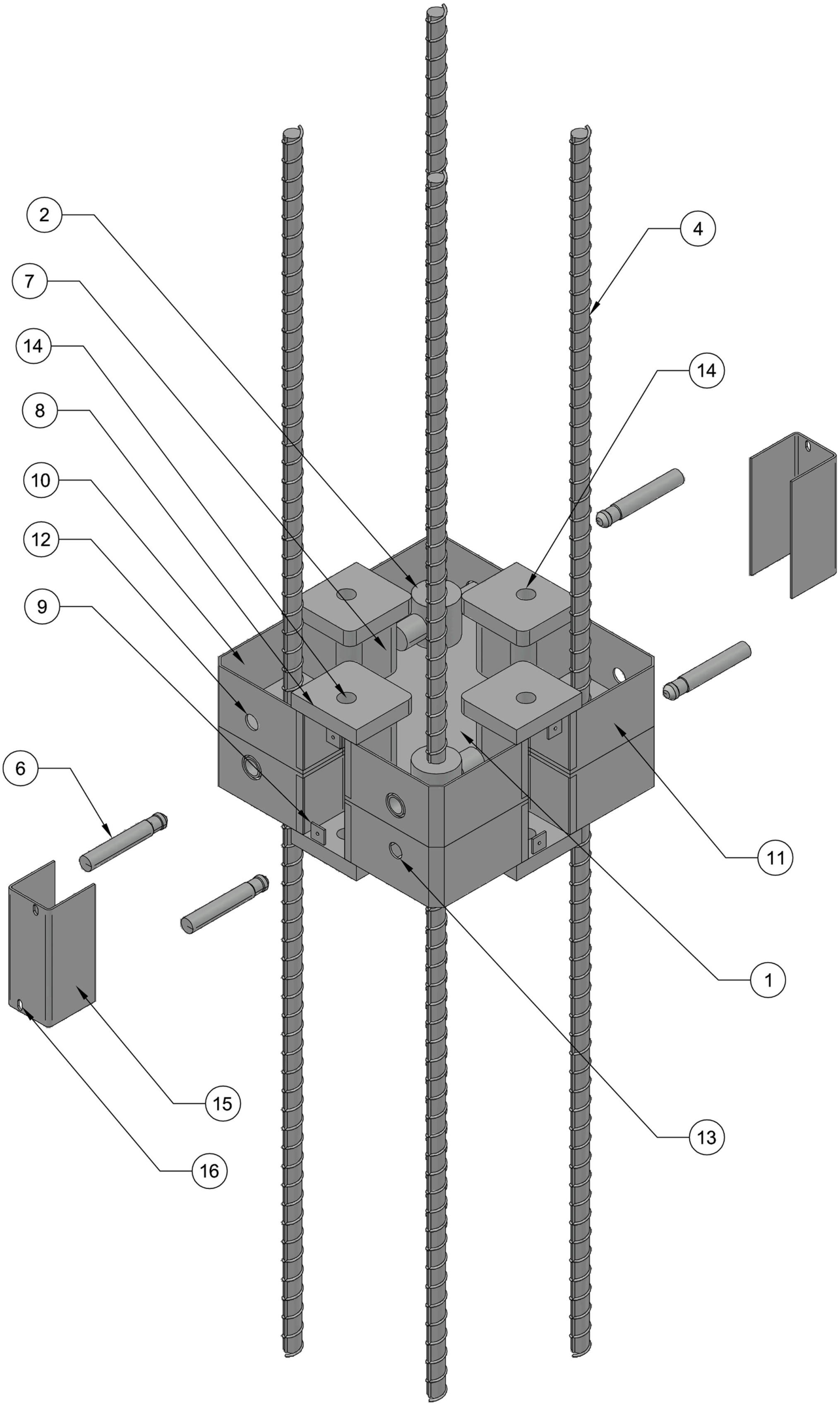

Fig. 4. Isometric view of assembled 350-mm DEP joint.

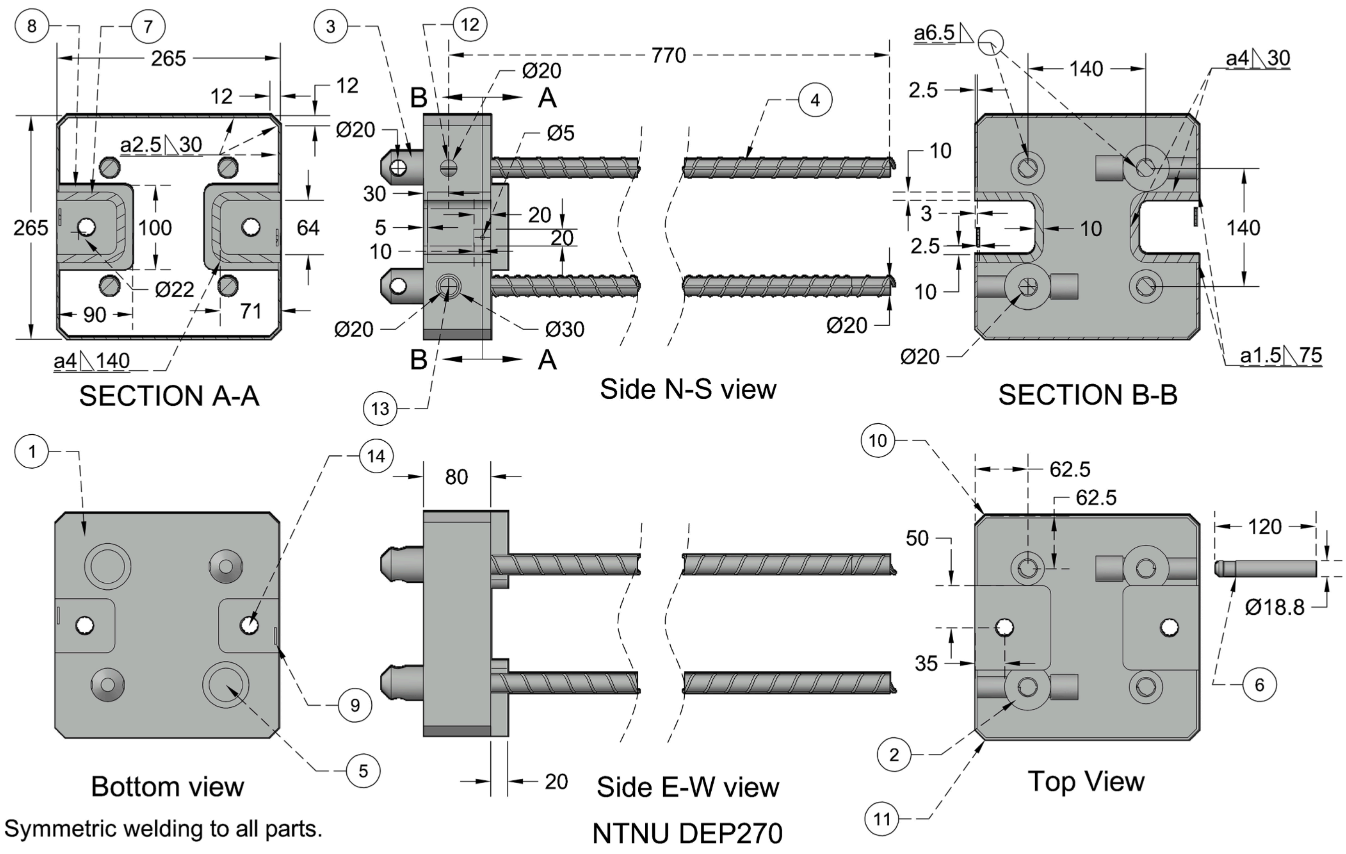

Fig. 5. Dimensional details of 270-mm DEP joint.

capable of manufacturing precast concrete piles, can cast energy piles using DEP joints [24,22].

Recently, two driven energy piles were installed successfully at the NTNU campus in Trondheim, as shown in Fig. 8, which proves that the technology is operating under realistic operating conditions and meets all of the functional requirements; hence, the joint has already achieved a minimum technology readiness level (TRL) of seven (European [8]).

3. Background

Energy piles are the deep foundations under the buildings that transfer the building loads to deep layers of ground or bedrock. Additionally, they can be used as a source/sink for heating/cooling buildings [10]. They can store heat at a seasonal scale, specifically during warmer seasons, and subsequently supply the energy for heating the buildings during the colder seasons [20]. Concrete energy piles can be classified as cast-in-place and precast piles based on the manufacturing method [25]. The majority of energy piles are cast-in-place since precast concrete energy piles were mostly single-segment piles. Single-segment energy piles have been investigated by [1]. The main challenge in the way of driven energy piles was the joints that connect the precast pile segments. The main reason why precast concrete piles are installed segmentally is that the shorter segments are easier to manufacture, transport, and install [12]. Several types of joints exist for precast concrete pile foundations [4,16], however, none of them could work for energy piles, as they do not facilitate the installation and coupling of heat transfer tubes at the joints. Fig. 9 shows the regular precast concrete pile joints and the DEP joint.

Although some efforts were made to patent the concept of precast concrete energy piles [17,11] and to introduce some types of energy pile joints [9,14,27], none led to a successful practical joint that could fulfill the industry demand. The main important characteristics of precast concrete energy piles are (a) being able to provide structural integrity between the pile segments, and (b) providing a leakage-free coupling of heat transfer pipes at the joint interface between the pile segments.

4. Application potential

Energy pile foundations are rapidly gaining ground in the construction industry as a sustainable method of supplying buildings with renewable and sustainable heating/cooling energy. The market share of driven precast concrete energy piles is expected to grow significantly in the coming years after the successful introduction of DEP joints into the construction industry. Potential applications of driven energy piles manufactured using DEP joints include but are not limited to:

- Residential/commercial buildings that need deep foundations to sustain and transfer the huge structural loads to deep competent layers of the ground, as well as a source for heating and cooling.
- Bridge foundations, where in addition to their structural role, can supply thermal energy for the de-icing of the bridge decks in cold seasons.
- Under the roads as a means of ground improvement, and supply thermal energy to the neighboring buildings and sidewalks.
- Integrated into DHC networks to increase their efficiency by reducing their operating temperature.
- Coupled with PVT panels to store their excess heat in the ground and increase the electricity production efficiency of the solar panels.

The annual precast pile production in the Norwegian market is currently at around 200,000–250,000 m, corresponding to between 13,000–17,000 individual piles, or 26,000–34,000 joints at a price of approximately 600 NOK per joint. If the shift from regular piles to energy piles moves forward as anticipated, energy piles should replace at

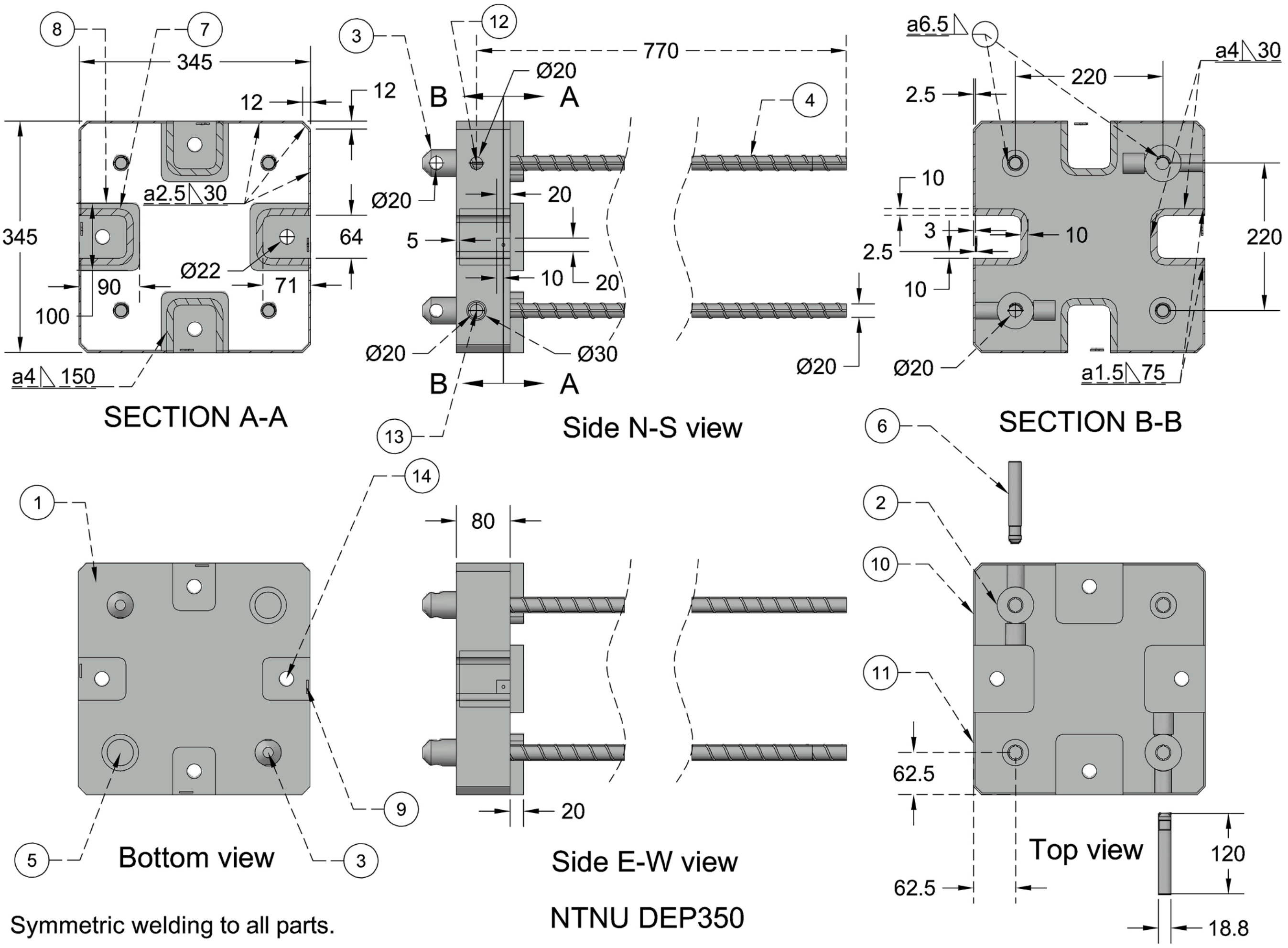

Fig. 6. Dimensional details of 350-mm DEP joint.

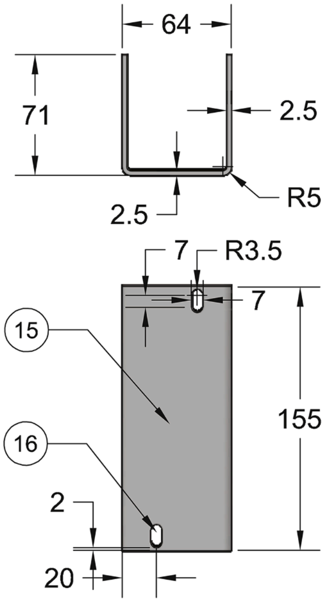

Fig. 7. Details of the shielding plate.

Table 1
Comparison of DEP joint types.

DEP joint type	Number of pipes	Width	Center-to-center rebar distance	Flexural stiffness EI
270	2	265 mm	140 mm	3500 kN.m^2
350	4	345 mm	220 mm	7720 kN.m^2

least a one-third of the supply of driven piles by 2026, generating a sales volume in Norway of approximately 8500–11,500 joints. With the 600 NOK/unit price for regular piles as a reference point and the annual cost savings from the electricity bill considered, the value of DEP Joint could be significantly higher.

A fractional cost of 100 NOK/joint could be recouped in as little as eighteen months. Adding an additional margin of 100 NOK/joint, which amounts to recouping the fractional investment over as little as three years, indicates a market of at least 6.8–9.2 MNOK in Norway, with a healthy margin. The payback time of precast concrete energy piles is shorter than other types of ground source heat pump systems such as borehole heat exchangers, and cast-in-place energy piles [19].

The other Scandinavian countries are very similar to Norway and a crude estimate indicates an approximate market size of 21–30 MNOK for Scandinavia in 2026. However, this is based on simple assumptions, more in-depth market research is necessary. It should be noted that both

Fig. 8. Installation of DEPs in Trondheim using DEP Joint, (a) after the installation of the bottom segment, (b) coupling the pipes after the top segment is connected to the bottom segment, (c) the pipe fitting after coupling the top and bottom pipes, (d) installing the shielding plate over the sidewall channel and riveting it to the joint.

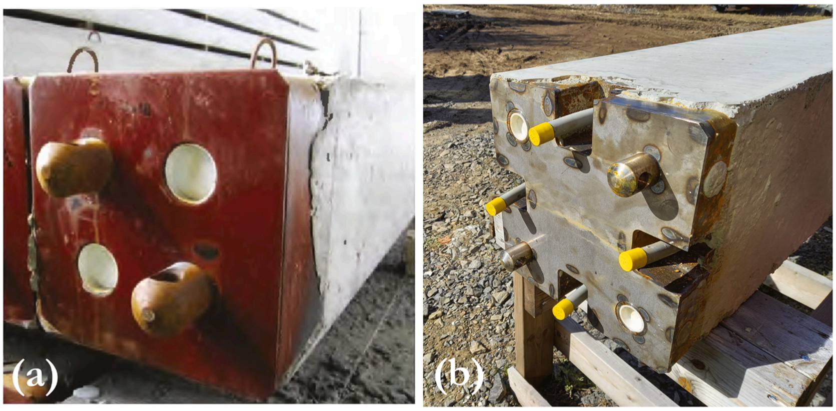

Fig. 9. (a) regular joints for driven precast concrete piles [6], (b) DEP joint.

Fig. 10. Global potential of driven energy pile foundations [25].

the market research and the commercialization of the DEP Joint should be carried out by the eventual license partner. Fig. 10 shows the potential countries to use DEP joint in the near futures.

Ethics statements

No specific ethics statement.

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CRediT authorship contribution statement

Habibollah Sadeghi: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Rao Martand Singh:** Supervision, Methodology, Conceptualization.

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.

Acknowledgments

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