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Geothermally activated mixed-in-place walls as permanent components of a sustainable energy system: case history

Geothermal activation of geotechnical construction elements facilitates the storage of renewable energy. During summer, solar energy is captured, stored underground, and subsequently utilized for winter building heating. In addition, the sustainable approach by using the mixed-in-place (MIP) method reduces carbon emissions and transportation burdens already during construction phase. The method's granular interlocking ensures efficient heat transfer to geothermal probes. Integrating geothermal activation right from the planning phase into building technology enables seamless incorporation. The synergy of geothermal activation and the MIP technique not only cultivates eco-friendly building concepts but also mitigates environmental impact across the entirety of a building's lifecycle. Geothermal activation and MIP can be applied to large-scale infrastructure projects, enhancing sustainability.

Keywords soil mixing; Mixed-In-Place (MIP); geothermal energy storage; Bauer energy wall

1 Introduction

Various foundation elements can be geothermally activated to use geothermal heat by equipping them with geothermal probes. The principle of an integrated renewable energy system is: By using solar collectors, for instance on rooftops, energy can be obtained in the summer months, fed into the ground via installed geothermal probes, and stored. In winter, this energy can be extracted from the ground again and used to heat buildings, for example. Geotechnical foundation elements which are temporarily used as static structure thereby take on an extended role and can become a permanent component of an integrated renewable energy system.

In addition to private construction projects carried out individually, geothermal heat can certainly also be used for large public construction or infrastructure projects and thereby significantly increase their sustainability. In particular, the concept of low-temperature heat and using the construction's subsoil for heat storage have the potential to make geothermal energy available almost everywhere.

In the area of geothermal activation, in situ soil-mixing techniques are considered to be ideal implementation methods due to the efficient heat transition from the soil to the geothermal probes, which are specially attached to the steel beams required for structural stability. The key for successful sustainable projects of this kind is to involve specialist foundation engineering experts in the planning from an early stage, for example, to consider the retaining wall as a sustainable medium for incorporating heat and cold storage beneath the building.

2 Mixed-in-place method

A Mixed-in-Place (MIP) wall currently has a nominal thickness of 40, 55, or 75 cm. In this geotechnical solution, invented by the specialist foundation engineering company Bauer, a binder slurry is mixed into the existing soil using a triple auger up to (currently) a maximum depth of 23.5 m to create a soil grout of homogeneous composition along the height of the MIP wall (Fig. 1). The installation of an MIP wall works best in well-graded soils with limited fines which contribute to a beneficial balance between fresh properties (like easy mixing and no segregation) and hardened properties based on concrete-like aggregate grading. Due to its special feature of mixing over height, for MIP, granular and cohesive soils can exist in particular layers. Also, in predominantly cohesive soils, MIP can be applied, but obviously, for achieving the

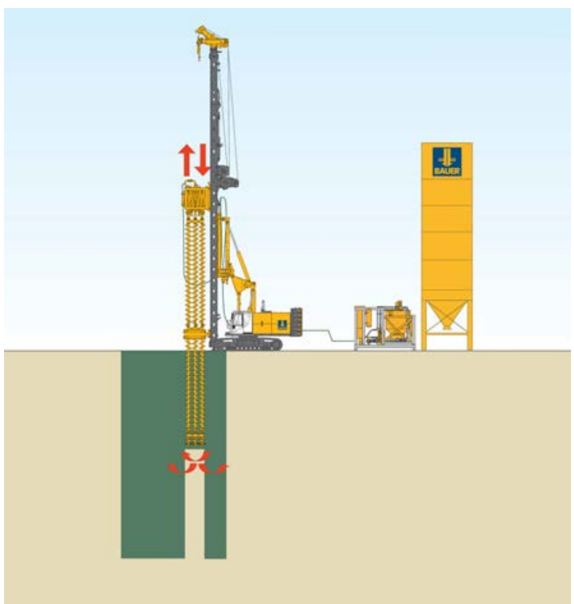

Fig. 1 Schematic diagram of the MIP method: The up-and-down movement and opposing rotational movement of the augers ensures the homogeneity of the soil-bentonite mixture. Source: Bauer Group

same strength, cement consumption and disposal volume will increase. A comparative study for economic and sustainable effects on the overall project level might still lead to a soil-mixing solution [1]. However, based on a comparable principle with regards to energy extraction, e.g., from the more cohesive soils, energy sheet piles can be an option [2]. The current limits of application of MIP walls have been and will be successively further extended based on corresponding project requirements and depending on the possibilities of equipment technology. The data listed earlier, together with technical requirements to meet, are filed in the general approval Z-34.26-200 from the “Deutsches Institut für Bautechnik” (German construction engineering institute) for the use of the MIP method to construct structurally relevant geotechnical elements. The application also extends to the permanent utilization of the MIP wall.

In order to build a continuous MIP wall in the ground, the panels are executed using the double-back-step technique. After the initial construction of two primary panels, secondary panels are constructed to subsequently close the gap between them along the intended wall axis. Afterwards, additional panels are installed across primary-secondary overlap areas so that, in the end, every section of the wall has been mixed at least twice. Steel beams are installed into the soil grout while it is still fresh, i.e., before the cement in the grout begins to set. After hardening, a compression arch between the beams can be formed within the wall section to transfer the earth pressure forces into the structurally acting beams, being strutted or tied back by discrete ground anchors.

3 Influence of the geotechnical solution on the sustainability of a construction

The equivalent carbon dioxide emissions (CO_{2eq}) generated for the construction of a deep foundation or other geotechnical solution are frequently being used to indicate the climate footprint of a construction product (also known as the Product Carbon Footprint = PCF). Apart from the carbon footprint, the required site-specific transport operations have a decisive influence on sustainability, since traffic volume represents a measure for noise and air pollution. The Carbon Calculator created by the European Federation of Foundation Contractors (EFFC) and the Deep Foundations Institute (DFI) makes it possible to systematically determine the PCF along with an objective and transparent comparison of geotechnical solutions for completing a construction task. These emissions account for the period up to and including construction, and therefore do not cover other factors from the building’s service life However, the figures determined using this calculator nevertheless represent a significant share of the overall life cycle assessment of a building [3–5].

Calculations of this kind can demonstrate enormous savings in carbon emissions that can be achieved solely by choosing alternative construction methods, thus proving the sustainability potential of soil-mixing techniques in particular (Fig. 2). For instance, a retaining wall constructed using the MIP method can reduce the PCF by 30 % or more compared with the conventional diaphragm wall method. Similar comparative calculations support the trend that the predominant share of emissions is due to the construction materials used. These findings lead to the conclusion that the potential reduction in PCF can be roughly estimated by evaluating the CO_{2eq} of the constructional materials [6].

Based on the same data collection, it can also be demonstrated that the reduction of transport to and from the site is another advantage of the MIP method. Only the binder components need to be supplied to site, ideally no disposal is generated by simply rearranging and cementing the existing soil structure. The significant reduction of transport is an independent and equally significant contribution to increased sustainability in geotechnical works, since noise emission and air pollution shall be reduced in the same order.

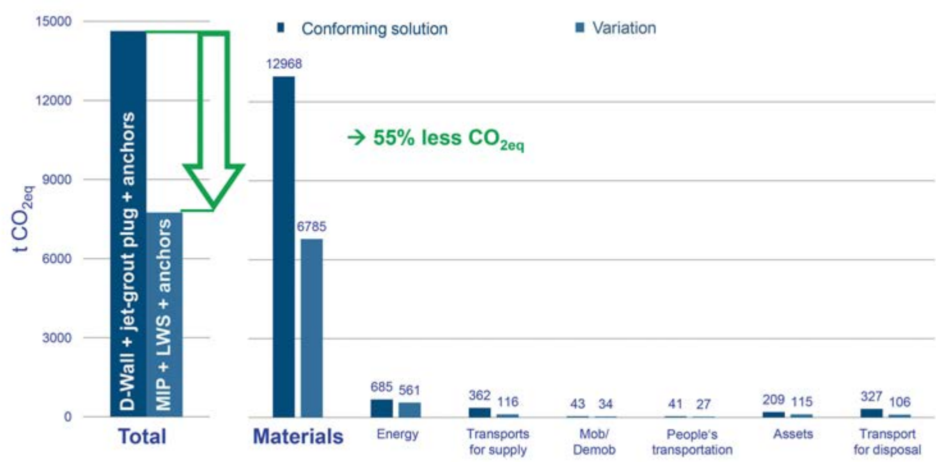

Fig. 2 CO_{2eq} assessment for geotechnical work on the QH Track (Berlin, Germany) when implementing the corresponding solution (DW + HPI base = diaphragm wall and HPI base) compared with the alternative (MIP + LWS = mixed-in-place retaining wall and Bauer LWS soft gel blanket). Source: Bauer Group

In principle, the sustainability – and also resource efficiency – offered by the MIP method is due to the construction of a material similar to concrete using the existing natural soil.

4 Geothermal activation of the soil

Making geothermal energy available for building services is not a new idea in principle. But the potential activation of temporary or permanent geotechnical construction elements is currently far from exhausted. However, apart from private homes like usually smaller residential construction projects, specialist foundation engineering has already made available geothermal heat for large projects like the award-winning "The Circle" project at Zurich Airport. For this major project in Switzerland, Bauer constructed bored piles that were geothermally activated [7].

Especially the concept of low-temperature heating-and-cooling technology offers a wide range of applications for geothermal energy. For example, geotechnical construction components are viewed as a central element of a system operated throughout an entire urban district based purely on renewable energy, in which the soil also acts as a storage medium to balance seasonal cycles in the system (Fig. 3). As a matter of course, the structural implementation of geothermal activation for geotechnical construction components must be considered at a very early design stage of a construction task in order to be integrated into the technology concept of the building. Given the fact that this is not generally the case at present, these should be incorporated a priori into the early planning process.

4.1 Case history Füssen

With regard to geothermal activation, deep soil stabilization structures such as those created using the MIP method are deemed ideal. Due to the granular interlocking of the soil with the soil-cement mixture (soil grout), heat is directed into the geothermally activated components without interruption (without a "cold joint") and transferred on to the probes attached to the steel beams. This idea is part of a patent that was granted to Bauer Spezialtiefbau. For a residential building with 14 residential units in the town of Füssen, Germany, involving the construction of MIP retaining walls, measurements show that the Bauer energy wall successfully produces 5.5 kW using just 1.0 kW of electricity, resulting in a measured power factor of 5.5, which is considered a very good value.

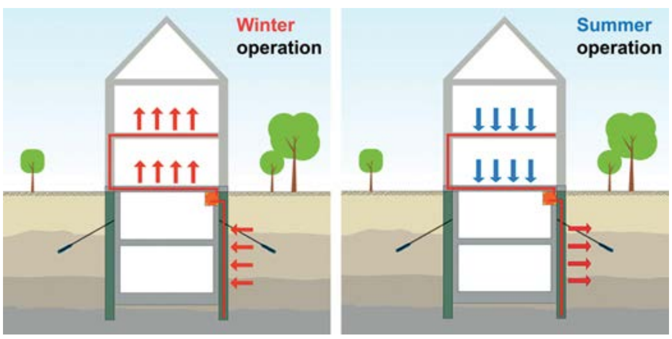

Fig. 3 Typical application for geotechnical construction components to use geothermal heat for a building. Source: Bauer Group

Fig. 4 shows the ground plan of the excavation pit that is enclosed by an MIP retaining wall. Vertical steel beams were installed as structurally functional retaining elements (Fig. 5). An analytical study determined the number of heat probes and the respective steel beams were equipped with the probes. This also includes the energy concept for the entire planned service life of the building. In this way, the temporary retaining wall actually became an integral component of the permanent structure.

The basis for a functional energy concept using geothermal heat is the suitability of the soil (combined with the wall itself), which must be determined in a preliminary survey and discussed with the owner. If the plan is to integrate the geothermal activation of the soil into the overall concept, the necessary approval must be obtained from the responsible local authority for water resources management. Bauer recently carried out an investigation on the long-term use of the soil for heat and cold storage. A calculation was made demonstrating that the energy gen-

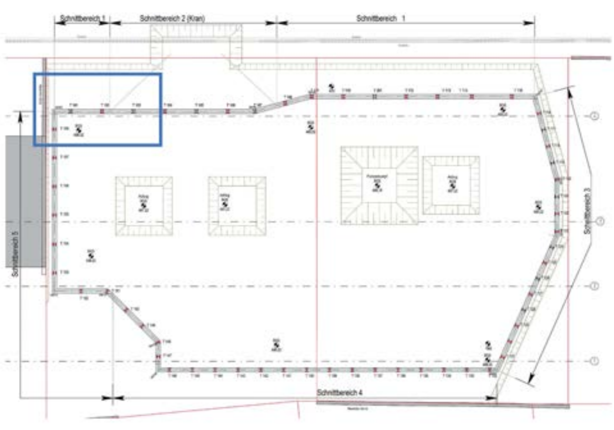

Fig. 4 Exemplary ground plan of an excavation pit with encompassing Bauer energy wall. Source: Bauer Group

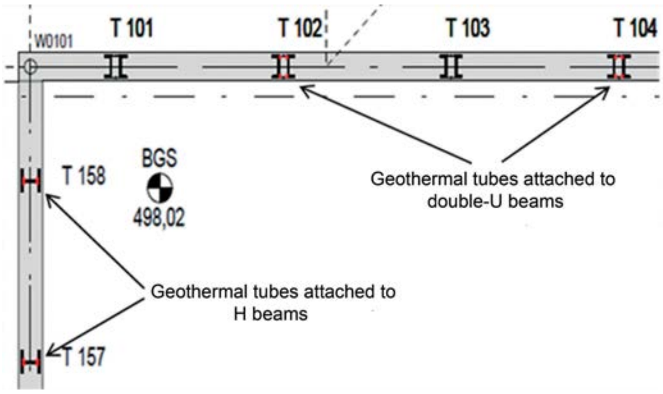

Fig. 5 Excerpt from Fig. 4 with MIP wall lining and single-wide-flange double-T beams or double-U beams and geothermal tubes (i. e., probes) to be installed in some places (marked in red). Source: Bauer Group

erated for the building during its operational life is realistically renewable. This was determined using thermal response tests (TRTs) and numerical simulations based on TRT [8]. Repeatable regeneration of the soil and groundwater is essential for the sustainability of the energy supply system. To enable recurrent geothermal use during winter months, heat generally needs to be transferred back into the ground during the warm summer months, while the lower temperature drawn from the ground is used to assist the cooling system of the building (see Fig. 3). This balanced overall use can be validated by numerical simulations which calculate the adjusted temperature of the brine circulating in the geothermal system over time.

The profile of the steel beams installed in the retaining wall also plays a role in planning and design. The geothermal pipes are normally attached to the inside of the beam, protected by the flange, with the specific connection depending on the details of the profile (Fig. 6). Because the brine contained in the geothermal pipes as a heat storage fluid needs to circulate through the pipes, they are designed as loops along the length of the beam.

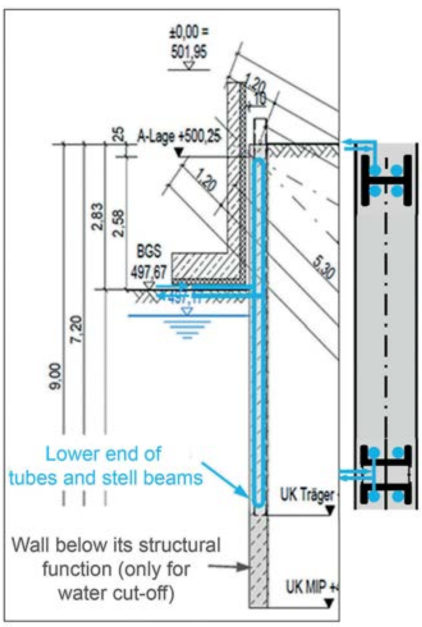

Fig. 6 Sectional view of MIP wall with geothermal tubes (i. e. probes) with culvert in the lower area below ground (left) and a schematic diagram of the culvert connections in the middle of a U-profile or on the side of an H-beam (right). Source: Bauer Group

Fig. 7 Lower end of a loop of geothermal probes, attached to the steel beams and ready for installation. Source: Bauer Group

For the residential building mentioned earlier, a basement level was designed and implemented using an MIP retaining wall with the structurally required steel beams for the encompassment of the excavation pit as well as geothermal probes (Fig. 7). The geothermal probes attached to the steel beams need to be coupled later using special connectors which are protected by steel plates for the installation process. The connections are guided out of the wall either at the side on the double-T beam or centrally on the double-U beam. On the heads of the steel beams, the connections of the geothermal probes may be above ground level and coupled there later on.

To complete the system or increase its redundancy, the system can be connected to solar panels – as was done in Füssen, Germany – to integrate another renewable energy source for the building system. Furthermore, the foundation slab can be geothermally activated, and the additional energy can be integrated into the system (see Fig. 8). After the building is constructed, the geothermal probes must be connected to the heating pumps. Then the heating and cooling circuit can be initiated.

5 Conclusion and outlook

Even in the future, it will not be possible to carry out construction work below ground without affecting the natural environment. However, all stake holders involved can work together to influence the extent to which this initial construction phase impacts the environment over the life cycle of a building. Specialist foundation engineering can also make a significant contribution towards more sustainable, “greener” construction. A cooperation based

Fig. 8 View into the excavation pit-preparation of the geothermal activation, here with the outlet of the geothermal probes from the MIP wall below ground level at the height of the future foundation slab. Source: Bauer Group

on partnership can facilitate joint development to find of the most sustainable geotechnical solution for the specific project, with few restrictions but innovative spirit.

Geotechnical structures are often temporary but should always be classified based on their impact for the entire life cycle of the total structure when they are constructed, thereby becoming an integral component of a sustainable building concept. One sustainable solution is to use geothermal energy via structural elements like retaining walls. The soil-mixing technique has stood the test to be an ideal method here. Apart from reducing the CO_2 footprint, fewer transports also result in lower noise emissions and air pollution in the immediate vicinity, thus also making a direct contribution to further sustainability goals. In particular, interlocking contact with the surrounding soil makes the MIP method a preferred sustainable technique to exploit geothermal energy because the heat transfer properties are favourable. In this way, the support structures that are often used temporarily become a permanent part of the technology in the building.

If the Bauer energy wall will be integrated into the technology of the building, planning needs to start at a very early stage. For structures with foundation piles or retaining walls which are already equipped with geothermal probes, these geotechnical elements can successfully become integral connectors for energy storage in the subsoil of a building. The basic idea starts with the owner and involves the consideration that local authorities provide support for renewable energy with a sustainable heating and cooling circuit. As soon as feasibility has been confirmed, an overall concept can be elaborated for the heating and cooling circuit of the building. In practice and in numerical simulations, it has been demonstrated that the use of geothermal storage through MIP elements and the surrounding soil can be an essential aspect of these sustainable concepts.

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