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Expected potential of bound and recycled backfill material in low temperature district heating networks

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Abstract

Special requirements for backfill material for district heating pipes are defined in the relevant standards and codes of practice. Sands shall be used in particular in the pipe zone around the pipe perimeter. Significant costs for adequate bedding material are reported unless sands are available in the local region. Because of this, the economic optimization of utilities has led to construction projects where the trench spoil is reused for the whole trench. Furthermore, the reuse of materials within the construction industry is a key element in achieving sustainable construction, with targets related to sustainability becoming an increasingly important part of tendering. Bound and recycled materials for backfilling are modern options for fulfilling these targets. Decreasing supply temperatures in future networks may mean that static design issues become a background concern. Mechanical soil issues preventing the application of bound and recycled materials will then only play a minor role. This makes new economic and environmental friendly backfilling possible.

Keywords: backfill; bound aggregates; recycling; district heating

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1. Introduction

1.1. State-of-the-art backfill material in district heating

For the installation of district heating pipelines, a trench needs to be built along the pipe route. The trench spoil should be stored near to the trench for refill; otherwise, the trench spoil shall be disposed of and replaced by a new material. Depending on possible contamination, a risk classification for the trench spoil shall be carried out before disposal. After digging out the trench, an adequate soil bedding of approximately 10 cm thickness for the pipeline is recommended. The pipeline is placed in its position in the trench and the different pipe sections are connected to each other. If necessary, insulation measures must also to be carried out. The trench is then covered with backfill material layer by layer. During the filling of the trench, each layer must be compacted to the required degree. This procedure is illustrated in Fig. 1.

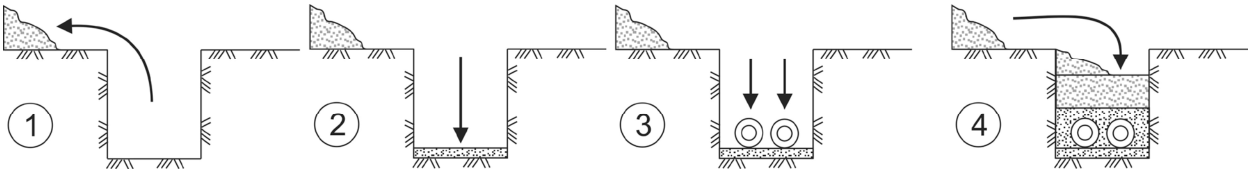

Fig. 1. Installation process for district heating pipes.

Strict requirements for backfill material for district heating pipes are currently defined in the relevant standards and codes of practice. The reason for this is an intense interaction between the pipe and the surrounding bedding material due to thermal expansion during operation. Because of the interaction between the pipes and bedding material, a pipe zone was defined. For Europe, the standard EN 13941 requires a pipe zone of at least 0.1 m around the pipe perimeter with granular backfill material [1]. Sands are allowed, which may contain single grains with a diameter of up to 32 mm. The percentage for fines with a grain diameter less than 0.1 mm may not exceed 15 %. Recycled material is not addressed here, thus not excluded. The German code of practice AGFW FW401 [2] limits the maximum grain size of the bedding material in the pipe zone to 4 mm and requires natural sands. Furthermore, requirements for bedding material for district heating joint testing were defined in a grain size distribution curve according to EN 489 [3]. These testing conditions represent an upper limit regarding the grain coarseness stressing the joints in a worst-case scenario. Developments for the European Standard EN 13941 summarized in prEN 13941:2015 [4] will allow grain size distribution curves within the limits shown in Fig. 1.

The qualities for the backfill material in the pipe zone were chosen to avoid unwanted cohesive interaction between the pipe and bedding material. The geotechnical models that were used for static calculation according to EN 13941 and AGFW FW 401 do not apply for cohesive soils.

Significant costs for the adequate bedding material are reported unless sands are available in the local region. Because of this, the economic optimization of utilities has led to construction projects where the trench spoil is reused for the whole trench. Furthermore, the reuse of materials within the construction industry is a key element in achieving sustainable construction, with targets related to sustainability becoming an increasingly important part of tendering [5]. A collection of bedding material currently used in Germany from [6] is compared with the requirements according to the cited standards in Fig. 2.

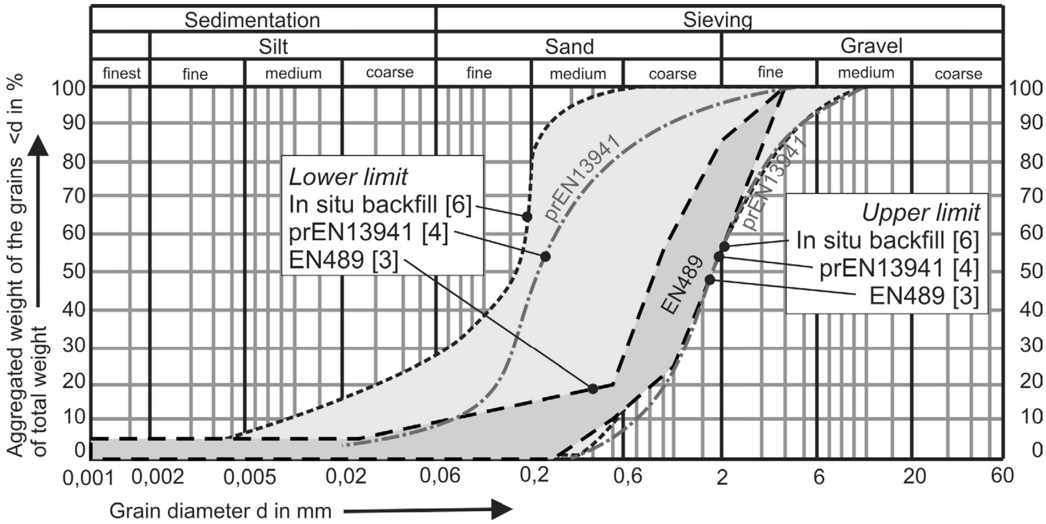

Fig. 2. Grain size distribution curves in district heating.

Discrepancies in the lower limits between different standards and experience in practice are illustrated here. The upper limits fit together well. Only the maximum grain size of the distribution curves according to EN 489 appears too small for a worst-case scenario in this standard. Furthermore, it must be noted that in situ material with a significant percentage of fines were also observed.

Nevertheless, as there are no known systematic damages related to having the incorrect bedding material in district heating networks; it is recommended that district heating systems contain the relevant reserves.

1.2. Bound backfill material

Backfill material can be used in an unbound or bound form. Unbound sands, as described above, are aggregates that are dominated by their mechanical intergranular behavior. To avoid settlements on the ground surface, compaction during installation is needed for these aggregates. Bounded backfill uses the spoil or aggregate and cement, with water and optionally, bentonite. Terminology varies depending on the region and product. The terms Controlled Low Strength Material (CLSM), Hydraulic Bound Material (HBM), Alternative Reinstatement Material (ARM), Cement Bound Excavated Material (CBEM) and the umbrella term Temporary Flowable, Self-Compacting Backfill Material (TFSB) have been introduced in Germany [9]. Here, the last one is used. However, despite the different terms, the desired properties of the material are mostly similar. The mechanical performance of bound materials changes with time (depending on the rate of strength gain), type of binder (rate and type of chemical reactions) and overall grading [7]. Compaction is not necessary for bound material because the stiffness is achieved through adhesive and chemical processes. Compared to other mixed-in-place material used for retaining walls, the major difference is the small percentage of cement and bentonite in the mixture. During the installation, TFSB flows into the geometry to be refilled. This filling process is illustrated in Fig. 3.

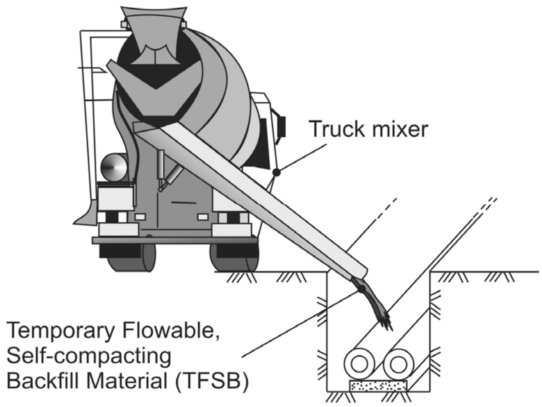

Fig. 3. The filling of a trench with TFSB.

The first single investigations into the application of bounded backfill material in district heating were reported in the late 1990s [8]. However, it is still an innovative technology in this sector today. The reason for this is very slow market development of this technology reflecting unwanted material properties on site (high strength instead of low strength). Nevertheless, accurate trench conditions can be obtained if the proper mix of the ingredients is used. Due to the environmental and economic potential, and advantages in the construction process, bound materials are used more frequently in district heating today. The application of bound backfill material for district heating pipes was investigated systematically for the first time in recent research projects [9, 10]. Additional adhesive contact forces between the district heating pipes and bound material were observed in experimental investigations in the laboratory and in the field. These additional forces put pressure on the pipe system, which is why the use of bound material is challenging at high operating temperatures. Standardized calculation procedures do not apply for this new bedding condition.

1.3. Recycled backfill material

Recycled (RC) backfill materials are aggregates derived from the reprocessing of inert material previously used in construction. This includes trench spoil, Recycled Concrete Aggregate (RCA), Recycled Asphalt Planning (RAP) and Recycled Aggregate (RA). Secondary aggregates such as recycled glass and incinerator bottom ash aggregates also apply for trench reinstatement in some countries. Recycled materials do not contain organic substances. However, in the pipe zone of district heating pipes, the special requirements for the bedding material also apply if recycled material is used. Thus, recycled sands from mineral demolition and construction waste are favorable. High quality RC-material is produced in local waste treatment plants. Nevertheless, quality control is required. A quality certification may contribute to keeping the quality of backfill material at the same prescribed level. Examples of recycled sands to be used as bedding material are shown in Fig. 4.

Fig. 4. Recycled material for backfilling in district heating systems.

The use of recycled material is not forbidden in trenches for district heating. In the pipe zone, the required grain size distribution curve must be provided (see Fig. 2). The backfill material shall not be sensitive to weather conditions and chemical reactions in recycled material shall be avoided for operational conditions at the surface of the service pipe. This includes the expected temperature conditions and presence of water. Furthermore, any chemical interactions between recycled material and the glues and adhesives used on the joints, must be eliminated.

Special attention must be paid to the frictional properties of the material used. Since district heating pipes expand due to thermal loads, an intensive interaction in the pipe-soil-interface is expected. The pipe statics depends on the skin friction, therefore the knowledge of frictional behavior of the recycled material must be as accurate as possible. Recycled sands from mineral demolition and construction waste contain crushed grains with sharp edges. The intergranular friction is in most cases higher than in natural soils. This must be taken into account in the static calculation. The second important property of the grains is their stiffness. Soft grains may be crushed due to mechanical wear and tear. This will lead to a change in the grain size distribution curve. The consequence is unwanted soil-mechanical properties, such as cohesive and adhesive material behavior.

Because of the variety of recycled material and its mechanical wear and tear, recommendations for backfilling recycled material in district heating are provided. The quality of the material and the installation shall be certified by an official quality certification or an official quality seal. The recycled material shall not contain any organic substances. A groundwater reservoir is not recommended along the pipe route where recycled material is used. The requirement for the grain size distribution according to EN 13941 is fulfilled. The actual interface friction coefficient between the pipe and the backfill shall be determined by a standard test. The resulting friction angle shall be used in the static calculation. If additional adhesion is observed, the consequences for the static calculation must be investigated. To avoid the crushing of grains, the grain density for the grains with diameter $d > 0.063$ mm shall be greater than $\rho_s > 2.566$ g/cm³. Unwanted chemical reactions in the pipe interface shall be avoided in operating conditions. The recycled material is to fulfill national environmental requirements. The recycled material in the pipe zone shall not contain bitumen and asphalt (significantly less than 1 %).

2. Recycling of backfill material in the European policy context

The European Commission adopted the Circular Economy Package in 2016, which sets targets and prohibitions, such as a ban on landfilling separately collected waste and among other things, concrete measures to promote re-using and turning one industry's by-product into another industry's raw material [11].

Firstly, the Waste Framework Directive (WFD) requires that: *"Member States shall take measures to promote high quality recycling and, to this end, shall set up separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors."*

By 2020, substitution of other materials using waste, including backfilling operations, shall be increased to a minimum of 70 % by weight. Concrete, bricks, tiles and ceramics are included in the scope of this target, soils and stones are not. What is more, the Waste Framework Directive (WFD) does not provide any definition for backfilling. The guidance from Eurostat confirms our special case to be qualified as a backfilling operation; "*A 'Backfilling' operation involves reclamation purposes in excavated areas or engineering purposes in landscaping, however it has to substitute other materials that are not waste. The condition of substituting other (non-waste) materials suggests that the reclamation or landscaping measures will be undertaken anyway, whether a suitable waste for this purpose is available or not."*

Thus, the term backfilling falls under 'other recovery'. 'Other recovery' is any operation meeting the definition for 'recovery' under the WFD but failing to comply with the specific requirements for recycling (or for preparation for re-use) [15].

Generally speaking, any suitable waste must meet requirements for the specific application and must be environmentally safe. Other stakeholders understand backfilling as being applied only to quarries and mines; "where anything else is to be filled, it must have a reason and there must be requirements for materials to be used [16]. Then, it is construction.

Having checked the conditions for waste falling into the category of backfilling, in our case the use of sustainable materials for pipe laying fulfills two out of three conditions; thus 1) the waste is used instead of other virgin materials (sand) and 2) it is suitable for the application, complying with the necessary properties for the particular performance.

The third characteristic “applied in a process of landscaping engineering” is not fulfilled if landscape engineering means shaping land and waterscapes.

The German Waste Management Act (Kreislaufwirtschaftgesetz, KrWG) explicitly excludes backfilling materials from the definition of “recycling”. In the five-step hierarchy pursuant to Article 6, according to which the ranking of waste management measures apply, backfilling is included in the “other types of recovery” together with energy recovery in the fourth position after prevention (1), preparation for recycling (2), and recycling (3). The last option always remains the same – disposal.

In Germany, backfilling is included in the list of eligible measures for fulfilling the goal of the substitution of non-hazardous building and demolition materials by waste to a minimum of 70 % weight by 1 January 2020.

To sum up this section, the advantages of using substitute materials are clear to legislators: reducing demand for virgin materials that could be used otherwise and the reduction of the amount of waste material otherwise dumped in landfill sites. Still, the definition is unclear as to whether the backfilling in the legislation relates to the landscape engineering only or includes backfill processes for laying pipes (category construction). Firstly, the new definition of “sustainable backfill material for district heating systems” must be proposed by the district heating sector and included in the legislation on waste. Secondly, the backfill material is not to be defined as the waste but as a sustainable product with certified qualities less severe than those applied for natural sands. Thirdly, the acceptance of the new material by the district heating industry will require some time and certification will make the final product more expensive than is currently foreseen.

3. Expected near future potential of bound and recycled materials

Using recycled backfill materials fits with the goal of boosting resource efficiency (creating more value while using fewer resources) [11]. Based on current technologies, the UK reports replacing 25 % of current consumption of construction materials by recycling construction and demolition waste [12]. Reuse of trench spoil may be one solution for fulfilling some of the EU requirements. However, in the pipe zone, special requirements also apply to the bedding material if recycled material is used. The overall principles behind recycling issues are to minimize general disposal of materials, demand on primary soil resources, material transportation and related fuel consumption and CO_2-emissions. Whereas prefabricated backfill material saves primary soil resources, the on-site re-use or recycling of material arising from excavation seems to be the most efficient method as this practice minimizes transport distance. Quality control and satisfactory husbandry of the recycled material are fundamental factors for accurate construction, avoiding unwanted mechanical or chemical interaction between a backfill and a pipe.

Nevertheless, the use of bound and recycled material in the trenches of district heating pipes has been cautiously observed by a number of district heating utilities for many years. The reason for this was the unknown and consequently incalculable interface behavior between pipe and unconventional backfill material during the significant expansion of the pipes in operation. For cold pipes, unconventional backfill material has been used in many cities for decades. This results in the evidence that the main obstacle for the broader use of recycled and bound backfill material in district heating is the operational temperature load.

However, some scientists expect a significant decrease in the operation temperature for future heat distribution networks [13], since this development supports the integration of low temperature renewable heat sources and low temperature surplus heat into the district heat distribution concept. A decrease of ca. $\Delta T = 50$ K in the next three decades was forecast in [13]. A sensitivity analysis with a simple district heating system shows that this suggested future scenario leads to minor role of static engineering and soil-pipe interaction issues [14]. This means low temperature district heating networks will make use of any possible environmental friendly bedding material.

4. Conclusions

Due to the intensive interaction of a district heating pipe with its habitat, proper bedding materials defined in the European standards EN 13941 are to be used. The German Code of Practice AGFW FW 401 also sets requirements on the maximum grain size of natural sands allowed for the bedding material. Transporting the adequate bedding material as well as removing excess spoil from the site significantly increases the costs for pipe laying. Many utilities in Europe therefore prefer to re-use the trench spoil for the whole trench, which will not meet the requirements according to EN 13941 in the most cases. As the future operating temperatures of the heat medium in pipes lessen the importance of the interaction soil/pipe and projects are more frequently evaluated in terms of sustainability, new materials may become suitable for backfilling. In this paper, firstly current requirements for backfill materials used in the installation of DH systems are described; secondly, additional requirements for the recycled backfill materials are listed; finally, this issue is debated in the context of the European and German waste policies.

Sustainable energy supply with renewable energy includes the integration of renewable heat sources at low exergy level and the connection of storage capacities to the networks. Because of this, an expected development in the district heating sector is a lowering of the network supply temperature according to some scientists. New heat resources may be recovered while heat losses are reduced. However, the network system is challenged by reduced efficiency at the production unit and increasing pumping power for the distribution. As far as the network design is concerned, the assumed reduction of temperature results in lower stresses and lowers displacements in the compensators. Compensating elements may be avoided or at least reduced significantly. Any predicted development according to this means a high potential for the use of new material in the trench since the interaction between the pipe and the backfill material is reduced to a minimum.

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