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IEA District Heating and Cooling

Programme of Research, Development and
Demonstration on District Heating and Cooling

Reuse of Excavated Materials

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Demonstration on District Heating

Reuse of Excavated Materials

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an excerpt from a project carried out for the Swedish District Heating Association.

More information

For more detailed information about this IEA programme please contact your country's representatives on the Executive Committee or Novem, the Operating Agent. Information is available on the Internet, http://www.iea-dhe.org

Preface and Acknowledgements

The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries. As an element of the International Energy Program, the participating countries undertake cooperative actions in energy research, development and demonstration.

District Heating is seen by the IEA as a means by which countries may reduce their dependence on oil. It involves the increased use of indigenous or abundant fuels, the utilization of waste energy and improved energy efficiency. With the same objectives District Cooling is getting a growing interest. The positive environmental effects of improved energy efficiency will give an additional and very strong impulse to raise the activities on District Heating and Cooling.

IEA's Program of Research, Development and Demonstration on District Heating was established in 1983. In the period between November 1983 and March 1997 under the auspices of the IEA 4 programs were carried out, Annexes I to IV.

In May 1996 Annex V has been started up. The following countries co-operate in Annex V: Canada, Denmark, Finland, Germany, Korea, the Netherlands, Norway, United Kingdom and Sweden. The Executive Committee has set following priorities:

- Optimization of operating temperatures
- Balancing the production and demand in CHP
- Cost effective DH&C networks
- Fatigue analysis of district heating systems
- District heating and cooling in future buildings
- Handbook about plastic pipe systems for district heating
- Optimal operation, operational availability and maintenance in DH systems

NOVEM is acting as the Operating Agent for Annex V.

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This report is part of the project "Cost effective DH&C networks" with the tasks

- cold installation of rigid district heating pipes
- new ways of installing district heating pipes
- reuse of excavated materials

The work on the task reuse of excavated materials has been monitored by the "IEA-Experts Group Cost Effective Networks" (EG) with Dr.-Ing. Frieder Schmitt from "MVV Mannheimer Versorgungs- und Verkehrsgesellschaft Energie AG (MVV Energie AG)", D-Mannheim, as project leader and chairman of the experts group.

The members of the Experts Group have been:

- Sten Tore Bakken, Norway
- Gert Boxem, The Netherlands
- Nigel Garrod, Great Britain
- Heinz-Werner Hoffmann, Germany
- Manfred Klöpsch, Germany
- Ture Nordenswan, Sweden
- Per Rimmen, Denmark
- Kurt Risager, Denmark
- Veili-Pekka Sirola, Finland

The chairman wants to thank everybody who has contributed and made it possible to carry through this work - especially every individual of the EG for making a good effort and showing a positive will to cooperate. A special thank to Mr. Nordenswan SDHA Stockholm and the team of SP-Swedish National Testing and Research Institute/Chalmers University of Technology, Göteborg for their special contributions of material from Sweden. SP (Mr. G. Bergström, Prof. U. Jarfelt, Mr. S. Nilsson) was subcontractor on this project. The Swedish contributions are attached to this report. The first entitled "Laying of District Heating Pipes Using Existing Soil Material" is

Content

1 Summary

On grounds of environmentally friendly construction the utilities are trying to use recycled material or industrial leftover instead of raw material as trench backfill. Environmental protection has been proven to not always increase construction costs, but also lower costs in certain cases. Priorities in the case of trench-backfilling are with the use of excavated materials because they are the least-cost alternative available.

Today's standard practice is the use of the before mentioned materials for the pipe and filling layers in the trench in combination with mechanical compaction. In the past serious quality standards were defined for materials and their manual installation to be applied in the pipe layer for reasons of pipe-protection. With the background of the current investigation these requirements may be loosened towards the approval of recycled material which seems to fulfill the demand for pipe protection just like the Swedish recommendation of 0/16 mm grain sizes instead of formerly required 0/4 mm. Further release of those rules seems possible in the future.

A very promising technology is the installation of the backfill material by hydraulic compaction. The material is mixed with water and a binding ingredient to form a fluid which then is poured in the pipe-trench. The fluid encloses the pipe entirely which takes away the need for costly manual compaction. However, the main economic advantage of this method is its reduction of required trench-width by about 30 cm when compared to manually compacted trenches. Thereby, the masses of excavated soil, backfill and reinstalled surface layer are reduced significantly. The application of this technique becomes interesting if the savings exceed the costs of the stabilized mixture. The prices for the mixture will possibly decrease in future due to higher volumes of production and a developed competition between suppliers.

Dependent on recipe, excavated soil may be almost exclusively used as the basis for the mixture (frequently referred to as SSM), if standard soil properties prevail. The casting of the pipes with fluid mixture seems to favor the use of coarse materials. By means of the fluidization coarser grains are encapsulated and their location fixed by fine ones. – The trench may be filled up to the street's level interface, above which the road will be reinstalled in a conventional fashion.

The above method of construction offers potential for further development in case that SSM will be granted the approval as frost-resisting road construction material. The trench could then be filled up to the interface on which the bituminous layer is installed instead of stopping the fluid refill underneath the support layer.

As a consequence, the cut-backs of the bituminous layer could be avoided which normally are required in the area of highly frequented roads to assure the quality of the bituminous joint between existing and restored surface. The construction-time has already been reduced significantly, the so called Single-Day-Construction became possible [18].

Even the simplest way of hydraulic compaction – the washing-in of backfill with water – has its justification in the construction of buried pipe systems. Soil and backfill need to be permeable to water. Admittedly, the compression is a little lower than with mechanical compaction but it is sufficient for pipe laying underneath paved areas with small loads like sidewalks or bicycle lanes. Also, it may be useful to add a step of final mechanical compaction to a pipe which has been washed-in in the first step.

This report is no construction guideline for the real case. It rather informs about the ongoing efforts aiming to ease the way for the use of recycled materials for the backfilling of pipe trenches in general. In the meantime, it is meant to catalyze the participation and discussion on the unsolved questions of this technique.

2 General

Besides the requirements for a long service-lifetime and low costs in the pipeline construction business aspects of environmental protection have become increasingly significant. It is urgently wanted that natural resources within and outside the construction site are conserved as much as possible. In this context fall the demands to restrict the transport of excavated material and backfill to a minimum and to avoid any unnecessary inconvenience for neighbors caused by the construction activities. For use in the construction site the before excavated material should be taken if possible and new material should be avoided for the backfill of the trench wherever possible. Conserving the resources can further be done by using recycled materials, industrial leftover or waste-material.

The calls for cost-efficiency and ecology don't necessarily exclude but may rather complement eachother in the case of pipeline construction. The elevated prices for new material and the frequently rising prices for the deposit of overburden both point in the same direction as does the call to protect the environment, i.e. to reuse existing material. Despite the fact that the cost relations and boundary conditions are varying within regions and even more on a national level since the access to resources underlies strong regional differences, the protection-constraints apply in general. Facing these constraints the utilities are trying to use advanced technologies since they are exposed to specifically high attention by the public as compared to private companies.

For the reuse of material for pipeline construction several interesting solutions exist at different places. In this report only construction methods will be described that may be transposed onto other places and their construction sites. The report will cover construction techniques which use mainly recyclable materials or recycled industrial waste. Furthermore, preinsulated bonded rigid pipe systems are assumed as pipe system throughout the report if nothing else is stated.

3 Introduction

Because district heating pipes are laid in street areas regulations of the road construction authority must be harmonized with the requirements of pipe installation to get a design-code. In the case of pipeline installation a high quality is required in order to legitimate the high investments by appropriately long service lifetimes. For the road construction it is necessary to keep the street's quality even after pipelaying underneath the pavement. Therefore, proper materials and tested methods are specified by regulation. The road construction authorities check the proper restoration of the street.

The current work focuses on pipeline construction from the viewpoint of an utility. It deals with the applicability of reused material primarily with attention to sustaining the quality of the pipe as compared to the use of approved backfill materials. Consequently, it does not deal with the approval of recycled materials for road construction. These regulations are done by the road construction authorities independently. However, it is obvious that road construction is opened to recycled materials as recent releases of guidelines show.

District heating pipes primarily need to be built in city-street areas, although one tries to put them in unpaved areas with resect to the high costs of road restoration. The soil in street areas mostly consists of inhomogeneous materials, only seldomly original ground is found. The overburden is made up of crushed road surface and, especially in historic towns from formerly dumped material, i.e. broken bricks and ships of foundation. The composition may vary from place to place within the service area.
In the following the relevant phases of construction with respect to the use of recycled material are discussed.

The initial step of construction is the excavation of the pipe-trench. The bituminous layers are separated from the other excavated material, because they are recycled. The street support is generally excavated together with the deeper soil layers. Mainly, the street support is made from coarse gravel, however, it may also consist of concrete which, in turn, results in entirely different chunks. The deeper soil-layers are commonly more homogenous and may be (dependent on geological situation) even from pure construction-sand. During excavation and storage the different materials are intermixed. The properties of the final mixture govern the reusability of the material. It may also be the case that the material largely contains organic components which are not useful for street support. Given such a situation the materials will have to be replaced completely.

The pipe is laid inside the trench together with all necessary accessories and fittings. Its outer casing is made from plastic and has to stay waterproof against moisture from the ground. It is put into a layer of high-quality fine sand which protects it. This sand layer protects the pipe shell and the muffs during the axial displacement which the pipe undergoes as a consequence of thermal expansion. In cooperation with the pipe manufacturers, who have to guarantee damage-free operation for a predefined period of time the utilities specify the requirements of the sand bedding exactly to rule out all possibilities of damage under the imposed tough handling-conditions during the road construction operation.

The backfilling of the trench has to be executed with extreme care because the pipe may not be damaged and the correct function of the accessories, e.g. expansion pads, has to be assured, also. At the same time these operations have to be finished early to minimize traffic-obstruction.

A further, relatively specific requirement for the buried laying of pipes originates from its later operation: The bedding forces acting upon the pipe casing shall be as uniform as possible. Since the static stress layout of district heating pipes relies on the friction forces between pipe and soil to compensate thermal expansion smaller bedding forces may cause higher displacements and consecutive damages. On the other hand higher bedding forces may overstress the pipe system.

Corresponding to all the above listed requirements there exist construction methods which were approved thus enabling the designer to build reliable and long-lasting pipe systems. In addition, the listing shall point towards starting points of making the pipe-construction cost-efficient by reusing excavated soil materials. These can be brought down to three lines of action which will be discussed individually in the following chapters:

1. The grains shall not be restricted to fine, round particles. Also crushed material with rather coarse sieve diameters shall be approved as bedding material. Thereby, processing of the overburden can be reduced, by chance it may be avoided altogether.

2. The sequence of construction may be simplified and shortened considerably if the backfill is not built in as grained sand but as fluid which hardens automatically after casting. With this, trenches may be built narrower since one does not need work-space for (manual) compaction.

   However, even with casted trenches grain size of the fluid mixture influences the trench width. Nevertheless, the maximum possible grain size seems to be desirable from economic reasoning. Furthermore, it looks like the casting of pipes favors the use of coarse grained material in the fluid because the later is encapsulated by fine grains during the settling process thereby saving the pipe casing from indentation-damages.

3. In cases where a direct reuse of the excavated material is not possible recycled or landfilled material etc. shall be used to reduce the need for virgin sands. (Recycling materials consist of mineral components which were used before in a bound or unbound way. They shall only contain minor percentages of bituminous material, brick stones, chalky sandstones or organic material if their envisaged use is as road construction material)

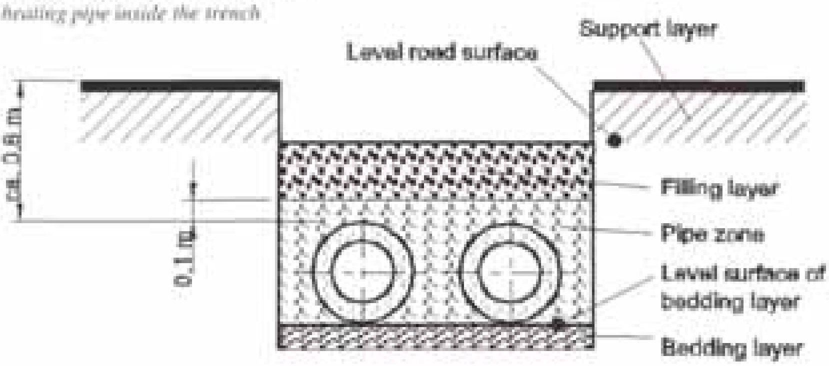
As suggested by the before stated this report is concerned with the efforts within different countries and in different locations to build district heating pipes cost-efficiently and, at the same time, in an resource-conserving fashion. For the reuse of excavated material no patent recipe can be provided since the materials available within reach of the construction site, the excavated soil, and the regulations of the road construction authorities etc. vary significantly. Here, solutions are presented that may be transposed onto different construction situations and that have the potential for being low-cost. Due to the fact that developments by the utilities, the industry and the research institutes are still in progress this report has to be looked at as snapshot of today's situation and today's opportunities. The aim of this report is to point towards ongoing research work and to support initiatives which break the way for the reuse of excavated materials.

4 Civil Engineering of Pipe Construction

4.1 Cross-section of the Pipe-Trench

The civil engineering for pipe-construction in street areas has to comply with the standards of the ruling road construction authority and, therefore, is relatively expensive. Stricter regulations apply for highways with heavy traffic load than for roads in residential areas.

Fig. 4-1: Cross-section of a district heating pipe inside the trench



The weakest regulations for backfilling apply in green areas where settling phenomena are of minor relevance.

With respect to the cross-section of a pipe-trench essentially three different zones have to be distinguished, the pipe zone at the bottom followed by the filling zone in the middle and the street support zone on top, as depicted in Fig. 4-1.
Within the pipe zone the layer underneath the pipe is often referred to as bedding layer. The bedding layer (level surface) is completed after excavation to enable correct support of the pipe.

If needed, a drainage is integrated in the bedding layer. The drainage may be placed centered under the pipes or off center on one side of the pipes, both options resulting in possibly thicker bedding layers. If the trench is to be artificially drained the bedding layer's material may not contain fine grained sands, e.g. the Swedish guideline for installation [2] requires minimum grain sizes of 8 to 16 mm.

The sand of the pipe layer is meant to shield the pipe against mechanical damages. The sand encloses the supply and return pipes entirely by a minimum thickness of 10 cm. Especially in danger are muff joints because they might have swelling edges and contain weaker components than the pipe casing, i.e. shrink sleeves resp. shrink hoses. For the pipe zone a material consistent of rounded grains of 4 mm [4] up to 16 mm [2, 3] is used.

In street areas the pipe zone has to be compacted carefully to prevent later settling of the soil. A Proctor density of minimum 97% is required for the pipe zone [3, 4, 5]. The cavities on the bottom of the pipe are the hardest areas to compact, especially the gap between supply and return pipe. Generally, they can only be correctly compacted by manual pounding. Here, the casting with a fluid autohardening mixture is a real alternative.

Compactable material specified by the road construction authority is inserted in the filling layer. It needs to be frost-resisting and shall not be conflicting with ground water quality (on the installation of concrete-containing mixtures refer to Chapter 5.3).

The street surface is commonly restored with exactly the same material that was used there before. If techniques of road restoration were to be used that don't require the cutting-back of the bituminous surface on both sides of the trench a major contribution to cost savings would be made.

4.2 Regulations for Construction

Within street areas primarily the regulations of the road construction authority have to be obeyed with the construction of district heating pipes. In most cases these are guidelines (with a long tradition) which are put down in a code of state-wide validity, e.g. Sweden [6] and Germany [5]. There, detailed instructions are given on applicable materials and the way how pipes, backfill, and pipe accessories have to be installed.

The backfill materials need to have the following properties:

Environmentally sound: The need to be clean of water-pollutants or chemicals corrosive to other parts of the system

Stability of volume: There may not be any significant settlings or upward-shiftings

Decay-resistance: They have to be sufficiently shock-, weather- and frost-resisting

Compactability: The size distribution of the material has to be such that if compacted its void fraction is less than 12%

Further influence on the way of pipe-installation is imposed by the pipe-manufacturer. Being liable for a warranty (usually 5 year) on pipe function and quality the manufacturer rules certain conditions for the installation of the pipes. The utilities have to comply with these rules if they want to be granted with the warranty.

Additionally, district heating pipes need to be installed in accordance to restrictions of pipe static. Varying operating temperatures expose the pipe to thermal expansion which is limited resp. eliminated by use of the soil friction and bedding forces. The static design anticipates specific bedding forces based on which measures for expansion-compensation are deduced. Only if the assumed values of bedding forces are reached and maintained during operation pipe stresses are kept below yield values. Even the axial displacements in the friction zone or the lateral movements in the area of expansion bends may not cause damage of the outside pipe shell. For these reasons of longevity a careful installation of pipes is an objective not only of the operator but also of the manufacturer.

Usually, the utilities have created specifications for the installation of pipes on a nation-wide level based on the above regulations supplemented by further technical standards [7, 8, 9, 10]. These specifications are custom-made for the requirements of district heating and contain further specialties. Such kind of specifications exist in all countries; here, the examples of [2] and [4] were already referred to, but one should also add the handbook [3] to the list which was published by the association of pipe manufacturers.

4.3 Available Techniques for the Reuse of Excavated Soil

Precondition for a recycled material to be used as backfill is that it is compactable. If the amounts of fine grains or organic material are to high a removal of the original material becomes inevitable.

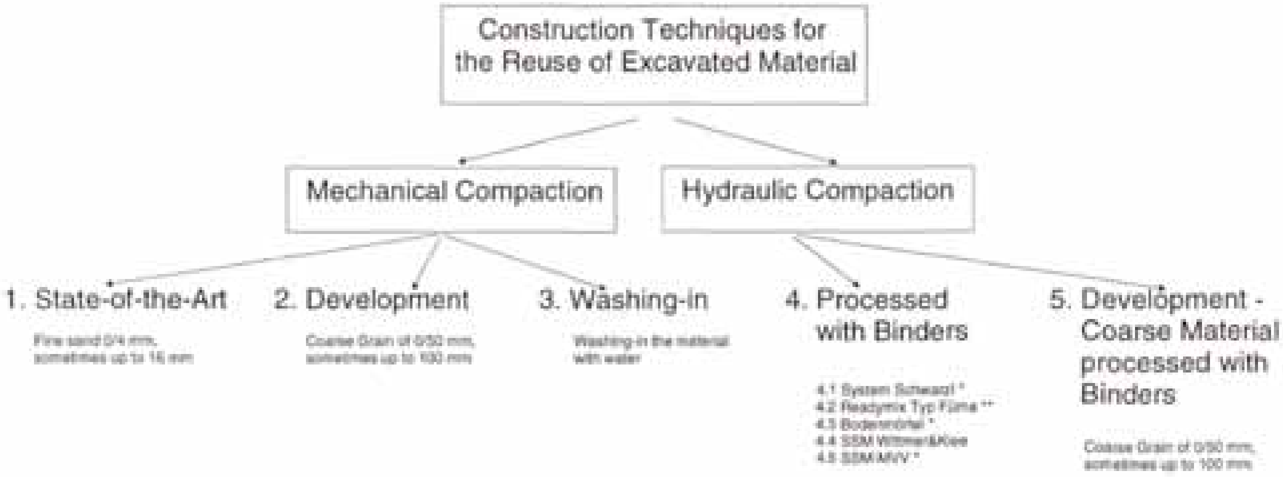
The excavated trench material might be infiltrated by large chunks of stone. Such material may not be used as backfill without processing. Coarse material prone to damage the pipe's casing has to be eliminated, e.g. by sieving.

Additionally, there is a possibility to process the overburden by mixing it with additives that change its properties towards a fluid-like material. The fluid, then, enables to backfill the trench easily and evenly which also takes away the need for manual compaction and does provide other advantages. The fluid-filling of the trench applied in any given situation will be referred to as >hydraulic compaction< throughout this entire report. The hydraulic compaction is to be looked at as antipole to the mechanical compaction of the usual grained and pourable construction materials. The mechanical compaction requires a remarkable amount of manual work and calls for larger trenches to provide space for workers since work has to be done inside the trench. In the case of trenches where manual work is applied and that are deeper than 1,25 m the German standards require side supports (slightly different ruling might apply in other European countries). If one were to eliminate manual compaction work inside the trench completely – i.e. by hydraulic compaction – the need for trench side supports may be taken away in appropriate cases.

The logic of reuse-techniques in pipe construction available today is provided by Fig. 3-2. These are listed with respect to their general advantages / disadvantages prior to their individual in-depth analysis given in Chapter 4. Today's standard is printed in the lower left underneath No. 1. Sand and gravel are used as backfill which is compacted mechanically. The filling has its full load capacity right after compaction. Disadvantages of this technique are found by the high degree of required manual work and the necessary extra work-space in the trench. The second column shows the proceeding of the conventional technique which is the application of coarser materials keeping the sequence of work-steps unchanged.

Column No. 3 in Fig. 4-2 depicts hydraulic compaction with water as the one-and-only additive, i.e. washing-in. The backfill is flushed into the trench by high amounts of water and, thus, compacted. This method is useful in water-permeable but not in cohesive soil. Generally, the required *Proctor* density values for road construction are not reached by washing-in. Therefore, this method may be applied for paved areas with small loads, like side-walks or bicycle lanes.

Fig. 4-2: Table of available techniques for the reuse of excavated material



General Advantages and Disadvantages:

Advantages	+ well proved construction technique + known material properties	+ less virgin materials	+ narrow trench + short construction time + less virgin materials	+ narrow trench + short construction time + less virgin materials ** controlled quality	+ narrow trench + short construction time + less virgin materials
Disadvantages	- wide trench - only virgin materials	- wide trench	- lower compaction density	- expensive processing - not load-resistant right after installation - material's specification uncertain ** only virgin materials	- expensive processing - not load-resistant right after installation - material's specification uncertain

Column No. 4 is concerned with the expensive processing of the backfill with cement as binder and other chemical additives. Several recipes exist for such a kind of processing into a castable backfill. In Austria, there is the patented recipe of the company Schwarzl; it is commonly know that some Austrian utilities apply this patented mixture. The Austrian mixture is only available inside Austria and in some areas close to the border so that independent developments had to be made in Germany.

In Mannheim, recipes were developed in cooperation with the superregional cement industry and also in Weimar a mixture was derived and patented.

The processing of the overburden with additives causes remarkable costs. But, these are balanced by remarkable savings. Most importantly the trenches may be smaller since work-space is not needed in the trench and, as a consequence, only a 10 cm gap needs to be left between pipe and trench wall. The expensive mechanical compaction is no longer required. The hardening-time of the backfill may be controlled such that extremely short construction times are achieved. However, long-term experience has not yet built up with this construction technique.
The last column No. 5 relates to a further development of the last described casting of district heating pipes. Coarse grained material is used as base in order to limit the effort for processing of the ingredients. Other than that, No. 5 material is mixed the same way as No. 4 and made castable just the same way.

5 Practical Considerations of Construction

The backfilling of the pipe-trench with pourable grained material is been treated in the following sections 5.1 and 5.2, more precisely, the first for fine and the other for coarse grained material. In the consecutive sections 5.3 till 5.5 the construction-situation after the backfill has been processed to a fluid-mixture is examined, more precisely, the case with just water or with other binding ingredients, i.e. cement, lime etc.

Soil is an inhomogeneous material whose complex properties are hard to assess. Even the friction for a sand-bedded body can often be described just approximately. The knowledge of the friction at the pipe-soil interface is important for the static layout of the pipe system. High soil-friction reduces the pipe-displacement thus yielding lowered efforts for expansion-compensation. If the friction coefficients have a large margin of uncertainty the layout safety factors have to be chosen higher.

Table 5-1: Specification of the backfill material for the pipe layer, taken from [3]

Grading:	Maximum grain size 16 mm 0.075 mm grains => max. 9% by weight or 0.020 mm grains => max. 3% by weight
Coefficient of irregularity:	$\frac{d_{60}}{d_{10}} > 1.8$
Purity:	The material must not contain harmful quantities of plant residues, humus, clay or silt lumps.
Grain shape:	Large keen-edged grains which may damage pipe and joints should be avoided.
Friction:	The material composition should allow such coefficients of friction as required by the installation plan following careful compaction. Those materials are recommended which can be compacted to the required level with a minimum of energy.
Compaction:	The friction coefficients of material are based on a standard Proctor value, average 97-98%. No values below 94-95% are allowed. Careful and even compaction is required.

The restraining friction force on the pipe is a product of the normal soil pressure and the related friction factor. The required precise knowledge of the friction force imposes the need for a smooth and defined bedding of the pipe in the soil. The construction has to guaranty that the pipe-layer which is made of sand or other material puts constant normal pressure onto the pipe during states of different operating temperature and over the entire service lifetime of the system.

It is well-known that a number of influences increases the uncertainty of the determination of the friction, especially

- uneven compaction of the pipe-layer
- channeling effects caused by radial thermal expansion of the pipes, more frequently in uncompressible bedding material
- the effect of ground-water
- extremely frosted soil (Scandinavia)

The static layout pays attention to these variable conditions by basing the calculation for compensation-measures on the lowest anticipated bedding force on the one hand, on the other hand by determining the material stress in the pipe assuming the highest possible friction.

5.1 Sand Bedding with Mechanical Compaction – State of the Art

At first, a level sand-bedding layer of 10 cm thickness is installed inside the excavated trench. It assures a stone-free bedding of the pipes, allows to level out the pipes and is, therefore, a prerequisite for a thorough execution of installation work. Apart from cases where a drainage pipe is installed – which is not commonly done – the same kind of sand is used throughout the pipe layer up to about 20 cm above the pipe's crown. In cases where a drainage pipe is laid a permeable sand with low fine-grain fraction is used. An example for the specification of the pipe-layer material is given in Table 5-1.

It reflects the requirements in Denmark which are obviously generally supported by the pipe manufacturers. Similar specifications exist in other countries. In Germany, however, a grading of 4 mm max. is required [4], sometimes 8 mm. Commonly, rounded mineral sand is used for the pipe layer. Recycled material is used only upon customer request.

The compaction of the pipe layer is expensive since the gaps between the pipes are hard to reach and because the pipes may not be damaged by the compacting operation. Figure 5-2 provides insight in the open workspace on which further restriction is put when the trench is braced. Bracing may be unavoidable due to imposed traffic loads, i.e. when heavy truck traffic is passing close to the construction site. Trench side support (bracing) may also be required as a consequence of work-safety regulations, e.g. when the trench is deeper than 1,25 m.

The sand has to be manually compacted up to the level of the pipe center. The pipes must be backfilled equally from both sides so they don't shift afterwards. Then, extra sand can be filled in layerwise and be compacted with small duty machinery.

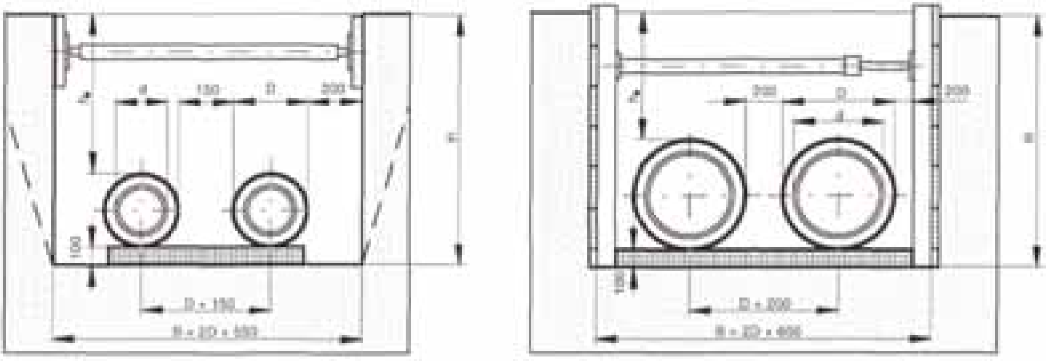


Fig. 5-2: Trench cross-sections for district heating pipes
Left: D ≤ 200 mm
Right: D ≥ 225 mm

Special care has to taken in the space between the pipes and also in the area next to expansion pads. This work has to be exclusively done by hand. As an alternative to manual installation of sand the road construction authorities allow the casting of hidden spaces with concrete, porous concrete or soil-binder-mixture [11]. With standard concrete delivered by the concrete industry the casting turns out to be too expensive, see Chapter 5.3.

For the backfilling of the pipe layer Swedish regulations allow for a grading of 16 mm (standard) and sometimes for 20mm, German for 20 mm. In the pipe layer underneath road surfaces a Proctor density of min. 97% must be obtained.

Different material may be used in the filling layer on top of the pipe layer. Preferences are with excavated material if it is sufficiently compactable. The latest regulations of the road construction authority permit to use recycled material in the filling layer which originates from recycled construction material or industrial leftovers.

The restoration of the street layer itself does not create any further difficulty since it has to be done the same way like the initial installation. The call for cut-backs of the bituminous layer on both sides of the trench, though, is an expensive undertaking. For one, the cut-back action causes expenses itself and furthermore the street-surface that has to be restored is widened.

Summing up, the above described civil engineering is state-of-the-art practice which proved success in the cooperation of all parties involved with road construction and has, therefore, been granted approval by the road construction authorities. The properties of the applied materials are known. The frictional interaction between PE-casing pipe and these materials is tested, although some questions still remain uncleared. It is a disadvantage of this technique that the installation of the sand requires relatively large space inside the trench causing it to be wide. Moreover, the installation of the pipes calls for a relatively high portion of manual work to compact the bedding sand. This procedure is time-consuming and expensive.

5.2 Use of Coarse Material with Mechanical Compaction

In order to reduce civil engineering costs there are attempts to lift toady's strict regulations for the bedding of district heating pipes in fine sands. It is a prerequisite for the approval of coarser backfill materials that the guarantied service lifetime of pipes may not be affected. This has to be assured by investigations with pipe materials and corresponding pilot field tests. The amount of research needed becomes obvious when one takes into account the wide variety of properties of excavated materials. First test results in this area are already published. In the scope of this report especially Swedish research results were taken into account [12], which were commissioned by Swedish utilities and industry and supervised by the National Swedish District Heating Association.

The most important results are presented in the following; an excerpt of the report is enclosed in Appendix 1 in English language. Especially, the behavior of the pipes was investigated, still, some questions were not cleared. A systematic test of the casing-muff-joints was not done, yet. Also, the tests were executed during a one-year time span so that no long-term effects may be concluded.

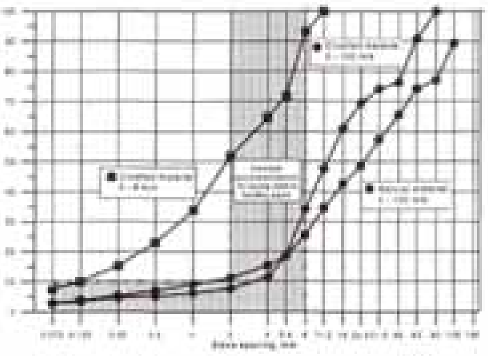


Fig. 5-3: Grading curves for backfill materials

It was the objective of the tests to expand the specification of approved backfill materials for the bedding of district heating pipes, if possible, to even include excavated soil and recycled construction material (but not in areas where sufficient friction has to be guaranteed). One was aware of the limitations of this contribution with respect to the topic; further investigations should have been initiated.

Within the Swedish work program a cost-analysis was done prior to the technical investigations. It did investigate on situations where the reuse of backfill yields optimum savings.

In the scope of this investigation three different situations of installation were picked:

1. City area, average pipe dimension DN 150
2. Suburban area, average pipe dimension DN 50
3. Green area, transportation pipe DN 250

The savings-potential for a reuse of excavated material was calculated for the three cases as follows:

- In city areas max. savings of 5% are expected if the overburden is put next to the trenches. These savings are even smaller if transportation of material through town is still required. In city areas backfill-material costs do not have a large influence on overall costs.
- Lowered costs of backfill have more effect in suburban areas. The civil work costs account for a smaller portion of the overall costs. By means of material reuse 9% overall savings are expected.
- The highest savings are expected for the case of transportation-pipes in green areas, if the trench may be backfilled with excavated material. In unpaved areas it is often possible to store overburden on the trench sides. Consequently, savings are expected to be as high as 19% and even higher.

5.2.1 Swedish Test Set-up

The Swedish tests did expose pipes of dimension DN 65 to extreme loads. The point was to check the capacity yield. Thereby, important conclusions can be drawn for the maximum load on district heating pipes.

It was investigated what kind of damage is done to plastic jacket pipes by two coarse grained materials, i.e. a material of grain-size limit 10 mm derived from two different sources. The one was relatively smooth-edged natural material, the other was crushed mineral material with sharp edges. As reference-material a fine grained sand with max. particle size of 8 mm was used which was no natural sand but sharp-edged crushed sand. This kind is considered equivalent to the conventional used material by the Swedish investigators.

Hence, the test were performed using these three materials of which the sieve curves are shown in Fig. 5-3.

These test were exclusively done using pipe dimension DN 65 with an external diameter of 160 mm. Besides the bedding parameters the properties of the plastic jacket pipe were varied.

Table 5-4: Calculated contact forces between stone and pipe DN 150/315, depth above crown 1.0 m; lateral movement 10 mm

		Contact force, N		
Stone size (side length) mm	Position of stone	Earth	Earth + traffic	At a bend (without traffic)
8	Crown	2	7	2
	Side	1	3	13
	Bottom	3	8	3
50	Crown	83	272	83
	Side	25	120	500
	Bottom	118	308	118
100	Crown	330	1090	330
	Side	100	480	2000
	Bottom	470	1230	470

The test parameters have been:

Backfill: 3 grain size distributions
- 8 mm crushed
- 100 mm natural
- 100 mm crushed

2 covering layer thicknesses
- 0.6 m and
- 1.0 m

Pipes DN 65 / 160:

3 wall-thicknesses of the casing pipes
- 2.5 mm
- 3.0 mm
- 4.0 mm

3 types of pressure resistances of the PUR foam (according to EN 253)
- 300 kPa
- 500 kPa
- 800 kPa

(Additionally, the measurements were carried out for a casing pipe of higher PE-quality)

During the tests a total number of 19 pipes was used each of which was 12 m by length. The overall length of the samples was divided into three sections of 4 m of which each was filled with one of the different backfill materials.

The test site was set-up such that the pipes were exposed to extreme traffic loads. They were built into a road that was exclusively used by large trucks of axle-loads of 220 kN. The bituminous layer was 12 cm thick. The duration of the tests was two month (2000 truck-passings) respectively 5 month (5000 truck-passings).

In addition to these field tests theoretical investigations and laboratory test were carried out.

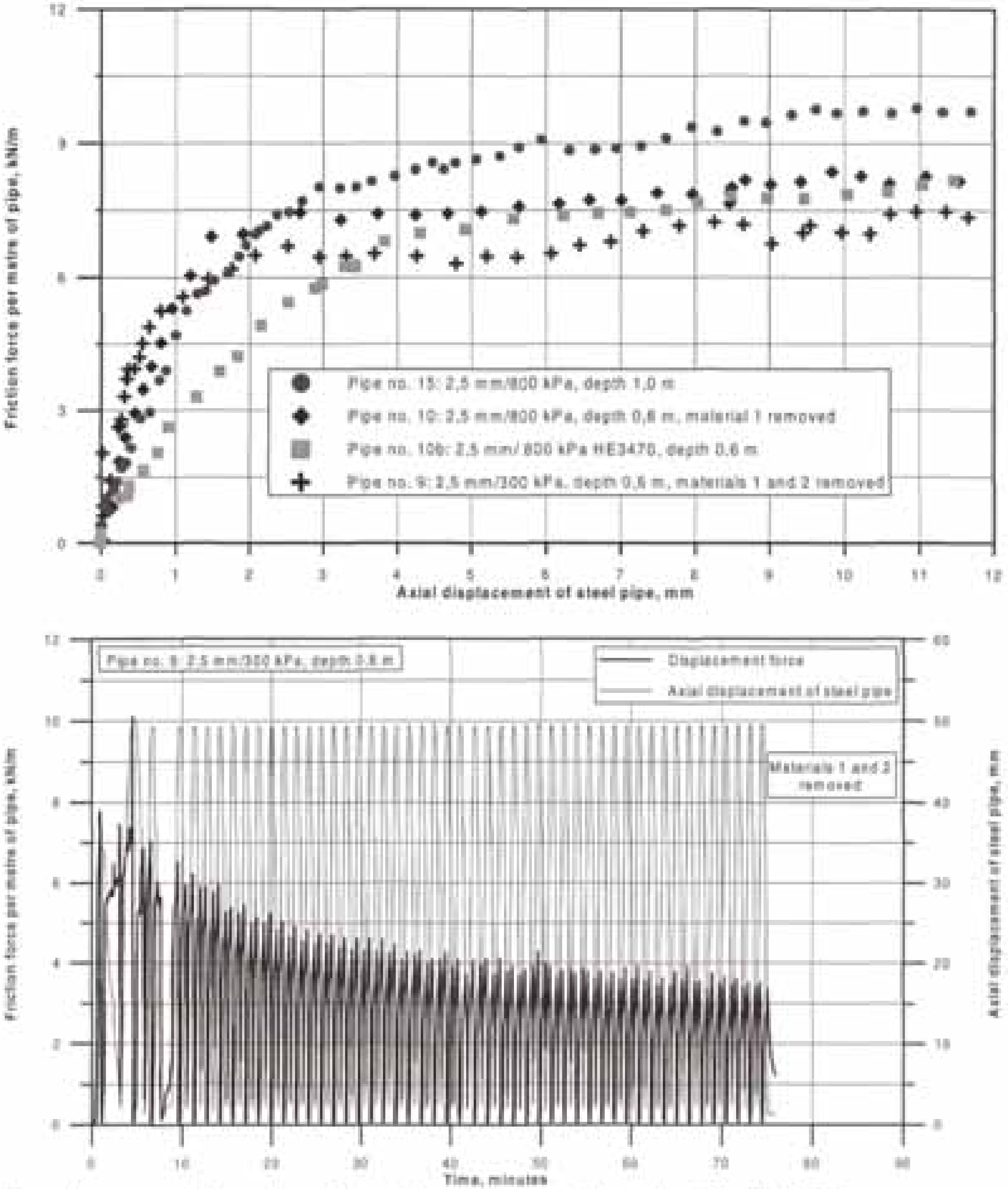
5.2.2 *Research Results*

The load on the casing pipe increases as a function of coarser backfill. This relation is depicted in Fig. 5-5, i.e. for a case where maximum forces are expected. Mostly, the peak load onto the shell is expected to be at the pipe's bottom if combined soil and traffic loads are acting on the pipe. In the case of side-shifts the peak load can be acting on the lateral crown of the pipe (the load-peak increases by the square of the max. stone-size).

The results of the force / displacement measurements have to be assessed considering the prevailing test conditions, i.e. high compaction for the pipe bedding. Measurements of the pipe outer diameter showed a shrinking by 0.5 mm.

Furthermore, the relation between axial force and resulting displacement was recorded. The result came out to be the usual leading edged curve with descending steepness, see top of Fig. 5-5. This is true for the initial displacement. For consecutive displacements the resulting force diminishes, i.e. the sand bed is loosened. A load cycle was 1,5 minutes long, see bottom of Fig. 5-5.

Fig. 5-5: Applied axial force for pipe displacement
Top: Initial displacement after strong compaction
Bottom: Diminishing force with movement cycles



From the measured low values of the axial forces the friction coefficients were derived, i.e. from the minimum values of Fig. 5-5, bottom, calculation scheme according to [13]. The resulting values were remarkably high:

1. Crushed sand 0 - 8 mm μ=0.73
2. Natural material 0 – 100 mm μ=1.16
3. Crushed material 0 – 100 mm μ=0.83

According to the Swedish authors' judgement the above stated values are statistically uncertain and, therefore, are not recommendable for use in a static layout calculation. Nevertheless, the values are good to base a comparison of the three backfill materials on them. The high friction coefficient resulting from the natural material is related to the large indentations which the stones create in the jacket pipe.

With respect to the damages of the pipe jacket a difference is made between indentations and scratches. The most serious indentations were recorded with the soft PUR-foam. They were up to 4 mm for a PUR foam of pressure resistance 300 kPa. In the case of the stiffer foam indentations were just half as deep. Figure 5-6 gives the distribution of measured values according to tested materials. The largest deformations were caused by the relatively

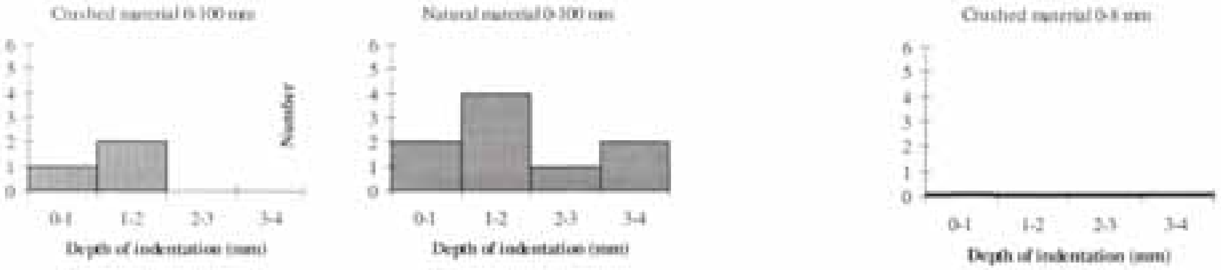


Fig. 5-6: Number and depth of permanent indentations, wallthickness 2.5 mm, 300 kPa, coverage 1.0 m

round-edged, coarse-grained natural material. On the other hand, the deepest scratches were caused by the coarse and crushed material. Figure 5-7 illustrated the results for the three types of backfill. Measured scratches were up to 0.5 mm deep, again, the maximum value in connection with pipes of soft PUR foam. The scratches were just half as deep with pipes of stiff PUR foam.

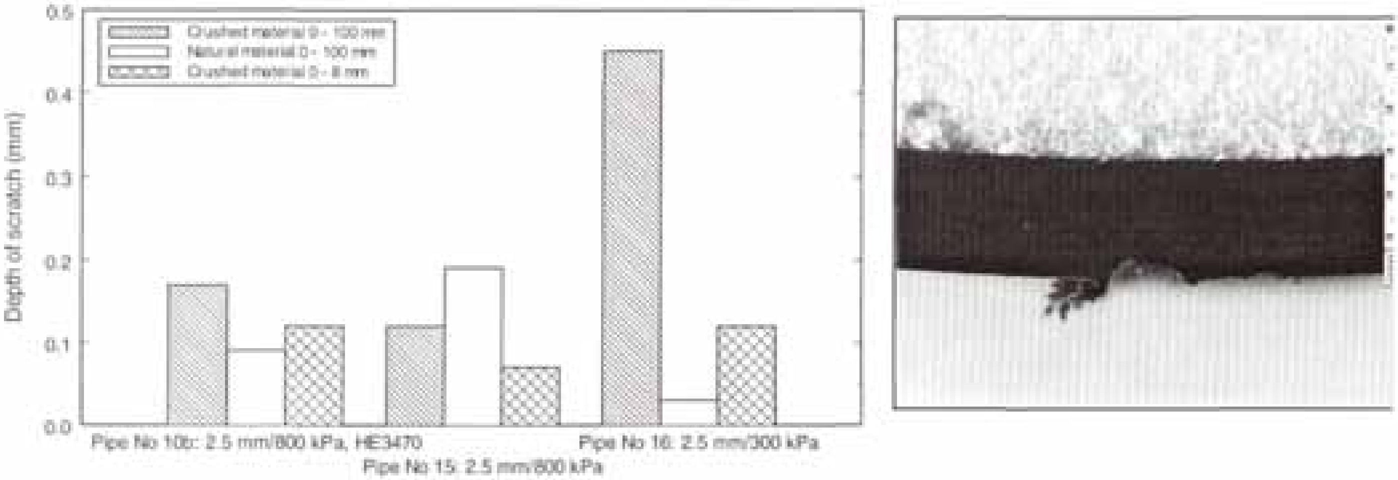


Fig. 5-7: Depth of scratches caused by axial displacement
Left: Distribution
Right: Cross section through worst scratches

Further details of the tests and their results are provided by Annex 1.

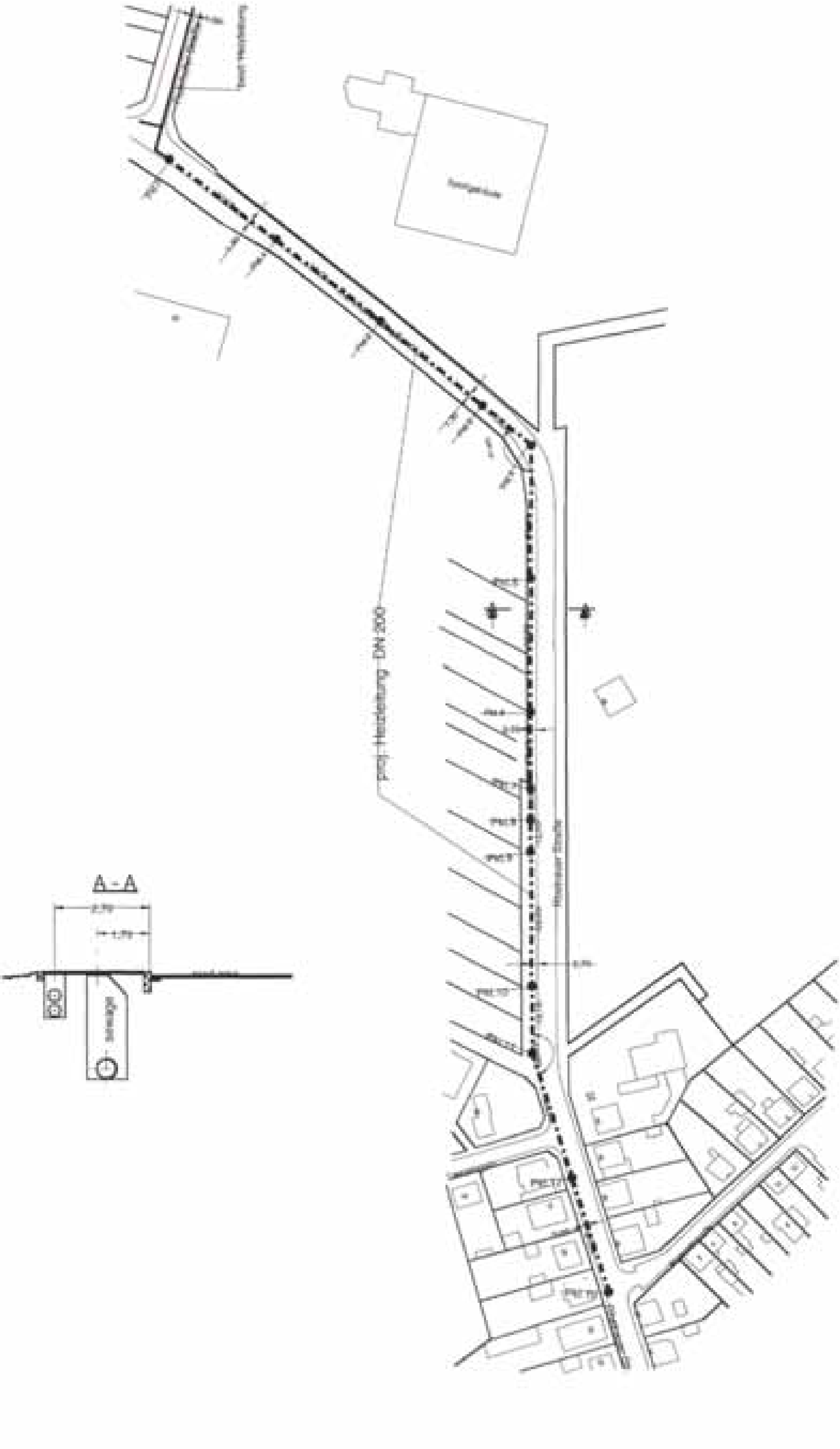
5.2.3 Assessment of the Results

At first, the measured values were commented by the authors. From their statements the following may be concluded:

- Crushed fine sand of 8 mm grain size with the related grading curve is giving equal bedding quality as natural sand
- For the pipe layer a natural or crushed material of up to 20 mm grain size is recommendable (grading curve as usual). Single large stones of max. 50 mm may be tolerated.
- Both the materials under investigation, the natural and the crushed, were containing stones of up to 100 mm size. These caused indentations of 2 mm and small scratches at a pipe complying with EN 253. Such pipe damages seem tolerable.

The load capacity of today's foam looks favorable and doesn't need to be raised. Even foams with a low pressure resistance of 300 kPa were accepted with attention to their maximum damage of 0.5 mm depth. It is recommended to maintain the wall thicknesses of the plastic casing as specified in EN 253. These wall thicknesses are sufficient to withstand the damages caused by the investigated coarse material. However, the conclusions and recommendations of the Swedish utilities are more careful. They are included in the new Swedish laying instruction [2]. Here, a maximum grain size of 16 mm in diam. for all layers up to 20 cm above the pipe's crown is required. The inclusion of stones up to 50 mm is permitted, but not in joint-areas – until the joints are proved to have sufficient strength. Mainly, the stricter regulations of the utilities are due to the fact that muff-joints were not put on trial in the tests.

Fig. 5-8: Pipe routing plan Rheinauer-Rohrhofer-Straße



The referenced laying instruction also requires a soft bedding in the area of extremely hard soil as rocks, or hard moraine in the region around expansion zones. This shall be assured by leaving a gap between pipe and trench wall of twice the outer pipe diameter for a length of 10 times the outer diameter around the bend [14].

More detailed information may be taken from Appendix 1 or, resp., the original report.

5.3 Washing-in with Water

The washing-in with water is a very simple technique to install the backfill. Even the hidden spaces under and between pipes are uniformly filled. However, this technique is usually not applicable in road areas since the required density of D_{Pr}= 97% is not quite achieved. The achieved compaction is generally sufficient for side-walks or bicycle paths.

Table 5-9: Requirements for Stabilized Sand Mixtures (SSM)

- The pouring action of the sand is executed with a thin fluid mixture to entirely fill the hidden space around the pipes
- The material must be removable by spate at any time
- The friction between SSM and PE-casing must comply with the manufacturers' guidelines for standard pipes backfilled with regular sand, i.e. $\mu \geq 0.4$
- The sand-characteristic must be maintained
- Measures must be taken to save the PE-muff joints
- The environmental acceptability has to be assured
- The approval of the road construction authority has to be attained
- The prove of frost-resistance has to be granted
- One day after installation the load capacity needs to be such that the trench may be footpassed and the street restored
- After a 56 day-period hardening shall be finished at latest
- Ways to dispose removed SSM have to be made clear

It is a prerequisite for washing-in that the soil and the backfill are well permeable to water. Washing-in is not allowed in the range of sewage installations because of the danger of hollowing them out. Also, the technique is not applied close to buried electric cables.

In the following, a case is described were washing-in of the pipe was favorable. The pipes in this route were put on top of eachother and were only twisted to horizontal in two locations where sewage channels were crossing in low depth. The supply pipe was put on the bottom where higher coverage compensates for higher expansions. Fig. 5-8 depicts the routing plan and the selected trench cross-section. Due to the vertical arrangement of pipes they could be placed underneath the side-walk for a large portion of the route. Because the strict regulations of the road construction authority don't apply in this area the pipes could be backfilled by washing-in.

Measurements of obtained compaction density are not documented. However, the pavement doesn't show any settlement even after a seven year period of operation.

5.4 Fluid Mixture with Binding Constituents (Stabilized Sand Mixture – SSM)

The installation of backfill can be largely simplified if the backfill is made fluid. Then, it can be poured in the trench like a liquid filling the hidden zones under and between pipes. Without having to step in the trench liquid backfilling assures a smooth bedding and compaction. The liquid backfilling can be done most efficiently if pipes are welded outside the trench saving the excavation of man-holes. In that case, trenches can be built 30 cm smaller which reduces the constructions masses considerably.

The SSM should preferentially consist of excavated material. For cases of unsuitable excavations recycled material or mixtures can be used. The material may not harden to a solid block that is hard to break up, but should rather stay with a sand-like consistency. The mixture should obtain a low solidity (pressure resistance 0,5 N/mm^2) such that it can be broken by a spate. It can then be removed like class III soil.

Primarily, two questions arise from pipe-bedding in hardened material:

- May the hard bedding affect the pipe and lower the service-lifetime?
- What friction can be expected to prevail, especially after several years of operation?

Without having commonly accepted test results some experiences from the practice of construction are provided in the following:

It is not anticipated that the pipes are damaged more than normal even if coarser material is used. The fluid material encapsulates larger stones such that these can not pose lumped loads onto the pipe jacket, e.g. in the case of axial movements in the expansion zone, [12]. Sharp-edged or flat grains prone to damage the pipe are fixed by fine grains in the mixture. Furthermore, the liquid backfill is likely to stay more homogeneous in composition than mechanical compacted material. Here, larger pieces are known to penetrate into deeper layers, e.g. from the filling layer to the pipe crown, during the process of vibration-compaction as a consequence of gravity. This effect will not show up in the case of hardened liquid backfill.

The frictional behavior of preinsulated pipes is discussed in greater detail in section 5.4.3.1.

Besides, the above stabilized sand mixtures need to fulfill further specifications. In Table 5-9 the general requirements are collected which are to be assured for SSM by today.

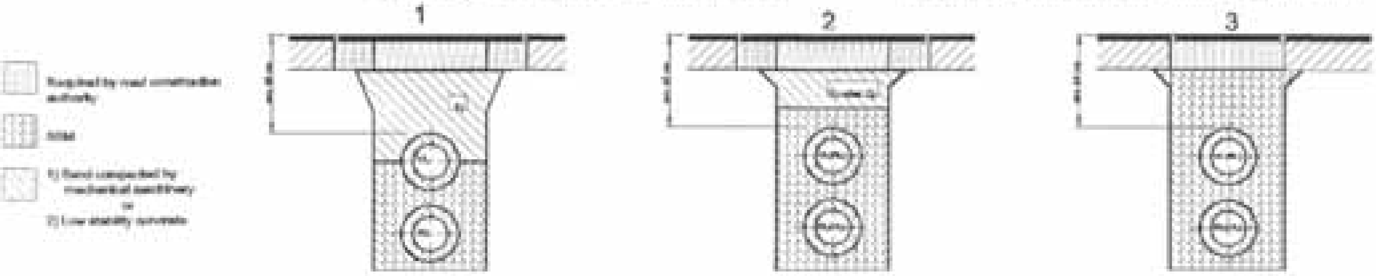
Besides the questions of technical applicability economy is the second criterion for the use of SSM. Stabilized sand mixtures are of interest for the utilities if they offer economic advantages versus the conventional sand bedding. This means that the cost of the conventional sand bedding are the upper margin for use of SSMs. From the viewpoint of the utilities the costs for SSMs are still to high at the moment. In future, more competition is expected which might bring the prices down. In Germany, the marginal costs for SSM are about 50 US $/m^3, see section 5.3.3.

5.4.1 Options for Installation of SSM

With respect to the requirements and properties of SSM mainly three options for installation are considered economically interesting. These are outlined in Fig. 5-10 by scheme together with a list of its major pros and cons (although this is done for vertical arrangement of the pipes it is still valid for horizontal arrangement without limitations). The SSM has to meet the conflicting requirements of an easy-to-break (removal) but highly load-resisting material (traffic load). The strength in the pipe layer should be about 45 N/mm^2.

In option 1 of Fig. 5-10 the pipe is casted with SSM up to the pipe-center. From there the further backfilling is carried out conventionally with sand. One can built small trenches and

Fig. 5-10: Options for installation of SSM



Requirements for SSM:			
- removable by spade	yes	yes	yes
- friction like sand	n.a.	yes	required
- directly applicable for road construction (ZTVA-StB89)	n.a.	n.a.	required
Advantages :	low quality requirements on SSM approved by road construction authority	small coverage possible (about 45 cm) approved by road construction authority	no pavement-cut-back at trench sides (savings of about 5-10%) small coverage possible (about 45 cm) quick construction work (no additional mechanical compaction required)
Disadvantages :	cut back at trench sides usually required (overlapping) increased sand quality (max. grain size 2 mm) increased coverage (about 65 cm)	cut back at trench sides usually required (overlapping) increased quality requirements for SSM + anchor bridge	high quality requirements for SSM (tests, quality assurance) + anchor bridge not yet generally approved by road construction authority (individual test with load plate experiment)

the bedding equals a sand bedding regarding friction properties. There are no concerns of the road construction authority against this way of using SSM.

Option 2 means, that the entire pipe is casted up to at least 10 cm above the pipe's crown during a single work-step. The further backfilling is once again done conventionally. It is the advantage that the pipe can be buried with small coverage. No special restrictions of the road construction authority apply.
Options 1 and 2 face the disadvantage that in order to correctly restore the street surface the edges of the trench have to be cut back to both sides. If this were not done cavities under the remaining bituminous layer may built up and be hard to fill by conventional methods.

This draw-back is overcome by option 3. There, the SSM is installed up to the bottom surface of the bituminous sublayer thus filling potential cavities on both sides of the trench by means of its good flow characteristics. The technique is very interesting since it reduces construction time remarkably, especially if the backfill hardens quick enough to allow consecutive work to be done early. It is a negative point that in Germany the material was not granted general permission as road construction material for the support layer / frost-resisting layer. Frost resistance has not finally been approved for SSM. However, it is anticipated that this property will be recognized by the authorities since similar mixtures were certified already. For this reason differences in applicability of SSM option 3 still exist between different cities in Germany.

5.4.2 Recipes for SSM

Experience shows that companies for ready-mixed-concrete also deliver concrete of lower mechanical strength which, for instance, may be used to fill cavities. For the most part, these construction materials don't meet the above stated requirements neither the technical nor the economical.

Today, there are some companies who supply appropriate SSM for the backfilling of pipes. But these companies just serve a limited region with their product. At least, across borders one will deal with different suppliers and different products.

One can assume that SSM is available everywhere, today. However, the recipes are not configured to use primarily excavated material. Partly, recycling materials and industrial leftover or even new materials are used. Two producers are known to have their product-recipes patented but the development of similar products doesn't seem to be hard.

The mixtures of four of the suppliers that are serving a larger region are dealt with in the following. Thereby, engineering issues from the customer's point of view are put first. As far as specific product info is concerned the reader is referred to the producing companies.
The four suppliers are:

1. Schotter- und Betonwerk (Gravel and Concrete) K. Schwarzl, A-8141 Unterpremstätten, phone.: 043 3135 520 720
2. Readymix Beton AG, D-40836 Ratingen, phone: 0049 2102 401 0, fax: 0049 2102 401 601
3. FITR-Weimar, D-99427 Weimar, phone: 0049 3643 769 267, fax: 0049 3643 769 257
4. Baustoffwerke Wittmer & Klee GmbH, Werk Mannheim, Essener Straße 57, 68219 Mannheim, phone: 0049 621 8041 30, fax: 049 621 8041 333

- SSM, Schwarzl type

Company Schwarzl was early in the development of a fluid backfill material for pipe-trenches. The material was first applied in 1980 at the Stadtwerke Graz, Austria, in order to backfill a pipe of dimension DN 300. This pipe was monitored so that a 20-year safe operation is verified until today [15].

Besides studies of environmental acceptability load-plate-pressure-tests and friction test were performed as mechanical checks. The measurements of friction yielded higher values than would have been with sand bedding. With these it is concluded that reduced end displacements allow less compensation-effort when SSM is applied (in Graz, the higher friction is not utilized; rather are standard values of sand bedding taken as basis for layout).

In Graz, one was fearing a drop of the hardened mixture's high friction coefficients over time thus causing the pipe displacements to rise. For this reason the above pipe was monitored. After a time-period of 11 years still no displacements out of the original location were recorded that were beyond the layout calculations.

Company Schwarzl offers the service to adjust their recipe to the individual soil conditions of the customer. This way, the interested customer is able to have his excavations processed such that the backfill meets the specifications required for pipe-bedding.

In the course of time the Graz-technique was adopted by other Austrian utilities. It is known that the Austrian Association of District Heating Companies is working on an instruction which standardizes the properties of SSM.
A draft version exists since 1998 [16].

- Backfill, Readymix type

In Mannheim, Germany, one tries to utilize the advantages of liquid backfilling of district heating pipes since the late 80th. One carried through various tests, both, with the above described Schwarzl-type and with other recipes. Primary research-topics were:

1. Friction PE-casing / SSM
2. Hardening Time, possible sequence of construction works for road restoration
3. Environmental assessment

The results of topic 1 and 2 are focussed on in section 5.4.3. The environmental assessment yielded no concerns against the processed materials nor against the additives.

Consequently, it can be certified by the producer.

The cooperation between the companies MVV and Readymix seemed promising on grounds of the international service of Readymix thus yielding the option of far reach deliveries.

However, although the Readymix material is suited to backfill district heating pipes, it must clearly be said that the material does not use excavated or recycled ingredients. On the other hand, the material can be quality-checked which is only possible with exactly specified ingredients (i.e. virgin materials).

Table 5-11: Boundary conditions of the published friction measurements with SSM

Test series	Nominal diameter	Coverage [m]	Test length [m]	Temperature [°C]	Remark
1. Graz, Austria	DN 25 DN 80 DN 150	0.3 0.92	2.8	10	
2. SP Göteborg, Sweden	DN 65 / 160			20	3 grain sizes
3. Mannheim, Germany, 1990	DN 200 / 315	1	7	Variable 10-80-130-80	Series 1: variable SSM-mixtures
4. Mannheim, Germany, 1996	DN 80 / 160	0.82	5.5	10 90	Series 2

- Backfill, FITR Weimar

The research institute for civil and pipe engineering FITR, Weimar, took the Mannheim-ideas and derived another SSM which it called 'Bodenmörtel' (soil-mortar), patent No. DD 259 393. The recipe, installation guidelines and additives may be ordered from FITR. The additives are available as dried substances. The FITR offers the service of customizing the mixture for special situations and to monitor the construction.

The Bodenmörtel consists of round about 93-97% excavated soil which may also be recycling materials. Consequently, the mortar is prepared at the construction site or a centralized mixing site, depending on economics. If the excavated soil contains large stones it has to be sieved before it can be used for the mortar. Highly cohesive soil with high water contents are not suited for the use as mortar. The processing machines equal the ones for regular concrete [17].

In the case of Bodenmörtel no measurement results were published for achieved friction coefficients yet. Ongoing measurements will probably be finished in summer 1999.

- SSM, type Wittmer & Klee

Parallel to the other paths of proceeding MVV developed another mixture in cooperation with Wittmer&Klee, Mannheim, which allows for preparation at arbitrary locations and, therefore, frees the customers of the service-limitations of the other suppliers. It is the recipe No. 514 to which the measurement results in Fig. 5-13 are related; this mixture was used in the coarse grained backfill-tests in Göteborg, Sweden, refer to section 5.5.

- SSM, type MVV

Besides a minor portion of virgin sand the recipe SSM, type MVV, uses industrial leftover for the main part (70%). This is melting chamber granulate which was used for abrasive blasting before. The used granulate is mixed with concrete sand of 0-2 mm and additives to form SSM.

Summarizing the above it can be concluded that various options exist for the preparation of appropriate SSM. Here, even special solutions might help which incorporate resources from industrial production.

Priority should be given to the reuse of excavated materials. But, its use should not be obligatory. Since construction sites in the city center are often limited in space and, therefore, not suitable for the interim storage of overburden, it is not necessary that SSM be made of the exact same material that was excavated. SSM can alternatively be made from excavations of other construction sites, from deposited material other industrial wastes. Here, economic reasons prevail.

5.4.3 Mechanical Properties of SSM

When the conventional sand bedding is replaced by SSM it has to be checked to what extent the friction forces on the pipe shell are affected enabling appropriate design of compensation elements. Furthermore, the SSM-mixture is inserted in the street's supporting layer and, therefore, has to be strong and frost-resisting.

5.4.3.1 Friction Properties

As opposed to a soft sand bedding the SSM builds a rigid shell around the pipe. Usually, one considers thermal pipe expansion purely for the axial pipe displacement and designs the compensation measures accordingly. Radial pipe expansion is generally neglected since sand is sufficiently elastical (Radial expansion with large pipes is a specialty and not considered in this context).

There were concerns that in a hardened environment the radial pipe expansion may affect the friction even for small pipe diameters. The expansion may lead to a clamp-situation between jacket pipe and bedding. Also, cement containing materials are prone to shrinking when they dry out. Both effects would cause higher normal pressures thus increasing friction which would (by use of the same calculation scheme) lead to an apparently higher friction coefficient.

Higher friction forces may be helpful in fighting large displacements in order to reduce the size of expansion pads. However, it has to be checked whether the strength of the pipe's PUR-foam withstands the increased shear stress. Because of this, knowledge of the friction is critical for preinsulated pipes. Until today, only a few measurements with district heating pipes were published. In the following the results of four different investigations are described. Their most important test-boundary conditions are listed in Table 5-11. The experiments were done by shifting the pipes with hydraulic jacks and recording the resulting displacements.

The test series 1 and 2 were carried out at ambient temperature. The tests in Graz were pilot measurements where slow hardening mixtures were applied. The hardening time was about one week before they could be weight-loaded and built on. The measurements in Göteborg were also pilot-tests that should clarify if coarse grains in the mixture affect the friction conditions.

The Mannheim tests are the only ones where temperature dependence was investigated. The pipes were put to a temperature swing of 80/130/80 °C to check whether the above described channeling effect occurs even with small preinsulated pipes inside SSM bedding. During the second test series the pipes were heated to and kept at 90°C.

The tests of series 2 (SP Göteborg) are discussed in more detail in section 5.5 and Annex 2. The test results of series 3 (Mannheim series 1) are presented in great detail in the following text, the results of Mannheim series 2 only as pars pro toto. The first Mannheim series was not designed to investigate temperature effects but rather to search for an optimum recipe for the SSM. Especially, the hardening time was of interest until a composition was found that hardened quick enough. Only the results of the tests with the most promising mixture (No. 514, hardening time about 1 day) will be reported here.

The set-up for the Mannheim experiment in which the Schwarzl type mixture was tested is depicted in Fig. 5-12. The technical data of that test were the following:

Test sample: 8 pieces DN 200 / 315
8 m length each

Bedding material:
3 different SSM recipes as well as 0/2 mm sand as reference material
coverage according to test series 0.25 to 1.0 m

Test temperatures:
Stepwise 10 – 8 – 130 – 80 °C

The measurement with mixture 514 were taken after a hardening time of 17 days. The minimum force needed to move the pipe was recorded. The initial force was comparatively high and dropped with consecutive tests. The force was recorded not before the pipe broke loose. After a waiting time of 8 days the measured force had risen again obviously due to settling phenomena.

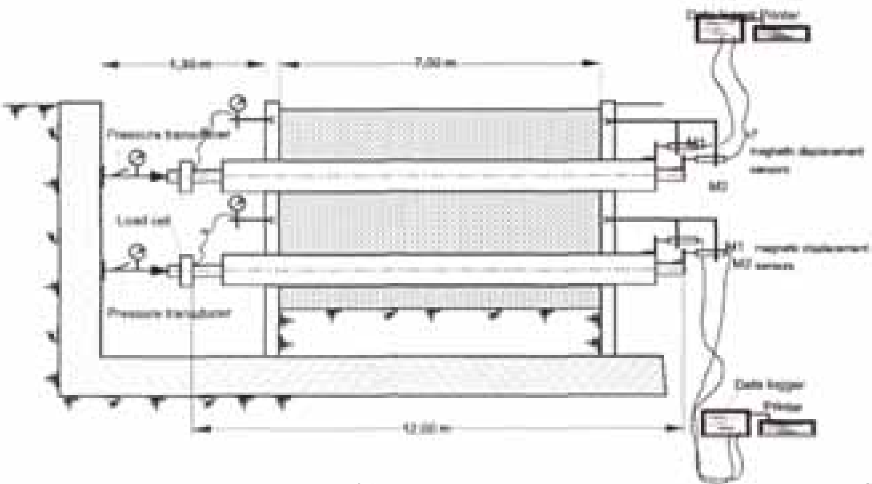


Fig. 5-12: Test set-up for the measurement of friction coefficients – series 1

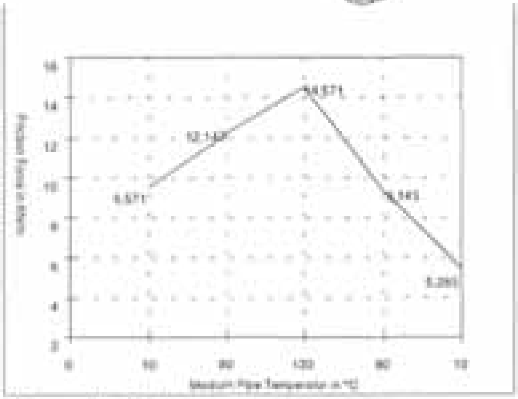


Fig. 5-13: Friction forces in SSM-mixture 514 at different temperatures

The results of the various temperatures are presented in Fig. 5-13. Higher temperature caused higher friction. The friction was about 1.5 – 2 times the value expected for sand bedding.

The second Mannheim test series, which was done with the Mannheim type Readymix was carried out in a similar test set-up, see Fig. 5-14.

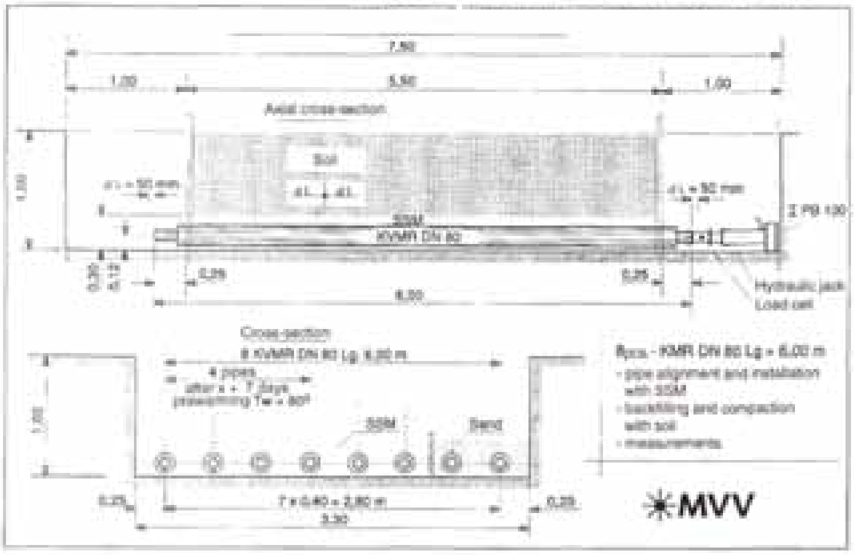


Fig. 5-14: Test set-up for the measurement of friction coefficients – series 2

The thickness of the SSM layer was 4 cm underneath the pipes and 10 above the pipes' crown.

Overall, the four described test series had been carried out to figure out the friction coefficients of SMM and preinsulated pipe in order to have reference values for the static pipe layout. Parallel to these measurements some were done with sand bedding for comparison. Still, a comparison between all the test is hard to make since influences like coverage, pipe diameter, and load were changed from case to case. Therefore, the recorded values were computed by the below formula to yield friction coefficients [3, 13]:

$$F = \mu \left(\frac{1 + K_0}{2} \cdot \gamma \cdot H \cdot \pi \cdot D_C + G \right)$$

with

μ	the friction coefficient
K_0	the coefficient of soil pressure, valued at 0.5 for sand
γ	effective density of soil = 18 kN/m³
H	depth of burial to the centerline of pipe
D_C	outer casing diameter
G	effective selfweight of pipe with water

All measurements that can be compared to one another are listed in Table 5-15. From these results it may be concluded:

- Experiments in Graz
  - the friction coefficient was about three times as the one in sand
  – if a SSM-line load is imposed afterwards then the pressure will not come to full effect, at least not right away
- Experiments in Göteborg
  – the friction coefficient in SSM was higher than in sand by a factor of 1.7 to 2.8
  – coarse grains generate higher friction (μ)
  – coarse grains don't hurt the casing pipes
- Experiments in Mannheim
  Series 1:
  – the friction with the cold pipe is 1.4 times the friction in sand rising to 2.8 times at 130 °C
  – when recooling to 10°C the friction drops to 60% of its initial value at 10°C
  – on the average of all considered temperatures the friction is 50% higher than with sand-bedding
  Series 2:

Table 5-15: Comparison of the measured friction coefficients

Test series	Nominal diameter [DN]	Grain size [mm]	Hardening time [d]	Temerature [°C]	Friction coefficient	Remark
1. Graz, Austria	150	0-8	7	10	**1.51**	Backfilled later
	150	0-8	28	10	**1.76**	
	150	0-8	28	10	**0.91**	
	80	0-8	7	10	**1.76**	
	25	0-8	7	10	**1.21**	
	25	0-8	28	10	**2.06**	
2. SP Göteborg, Sweden	65	0-8	15	20	**0.66**	Refer to section 5.5 and Annex 2
	65	0-32	15	20	**0.70**	
	65	0-90	15	20	**1.15**	
3. Mannheim, Germany, 1990	200	0-2	16	10	**0.57**	Series 1
	200			80	**0.72**	
	200			130	**0.87**	
	200			80	**0.55**	
	200			10	**0.32**	
4. Mannheim, Germany, 1996	80		2	10	**0.33**	Series 2 Füma R
			7	90	**0.48**	

– in series 2 relatively low friction coefficients were measured being μ=0.33 at a cold pipe. They climb with increasing temperature by 45% to about μ=0.48. (in the same test-site the sand-bed friction was evaluated to μ=0.48 – always taking the average out of 2 measurement cycles)

5.4.3.2 Road Construction with SSM

In the test-site which is sketched in Fig. 5-14 experiments with SSM-Type Readymix were performed (see section 5.4.2). With these, the hardening time and load capacity were measured. A major portion of the tests were the load-plate-experiments done after a certain hardening time. The objective was to reduce the hardening time in order to accelerate construction. Continuing the road restoration is possible not before enough strength of the SSM is achieved enabling to carry workers, machinery and new surface.

The results proved that the name *stabilized sand mixtures* was properly chosen. The mixtures did not harden to form a lump but rather stayed breakable and loose. They may be exposed to load-plate tests, even pile-drive probing is possible as crosscheck-measure.

SSMs are not permitted as road construction materials because the tests of frost-resistance are not yet available. However, they may be applied in the pipe and filling layers without limitations, but not in the frost-resisting layer. The loose support layer then must be constructed with common materials if the road construction authority insists in doing so.

Agreements with the road construction authority may be negotiated to allow the liquid backfilling up to the lower surface of the bituminous layer, especially in the case of streets with low rated loads. With this, experiences have been made in Mannheim since 1990. In three cases the backfill was done up to the bituminous surface. All three streets were monitored regularly and no settlements could be registered.

Fig. 5-16: Cross-section of trench Mannheim Meisenstraße, savings with road-restoration by use of SSM

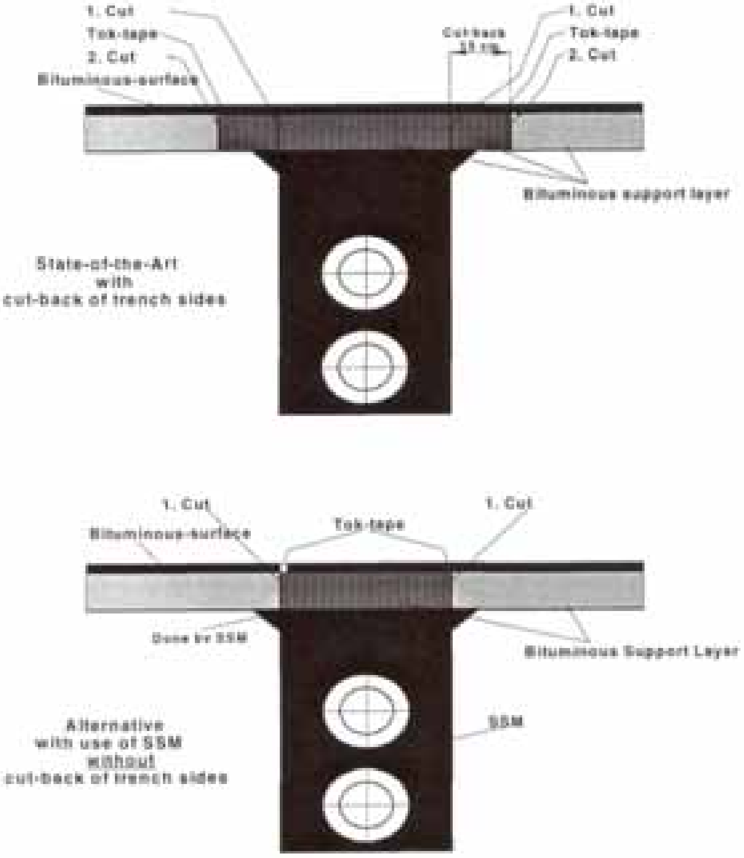


Fig. 5-16 shows a construction where the liquid fill was used up to the surface layer. The cut-backs on either side of the trench could be avoided. (This site was a district heating pipe of DN 80 and 100 m length where the trench was open for only one day from 8 am to 6 p.m. In the early evening residents were already allowed to cross the trench).

Fig. 5-17: Stone-shielding sheet to protect muff-joints

5.4.4 Construction and Costs

The just described investigations and test installations could be used to improve the sequence of construction. Further potential for cost-reductions does exist. When all experimental results are confirmed by scientific assessment they can enter daily work practice opening the ways for full utilization of all the advantages. For instance, the higher friction values of SSM may not be used today, because they have to be reconfirmed by check measurements. Current layout practice still anticipates the same low values as for sand bedding , see [3, 4, 13]. In Mannheim, anchor bridges [18] are still used in combination with cold installed pipes for the sake of safety. These bridges may be avoided if the friction is assured to be always higher and stay higher than with sand bedding. Also, not all the construction related advantages of SSM are yet fully utilized. Not before the frost-resistance is a certified property the material can be used throughout the trench bringing along the major time and cost benefits.

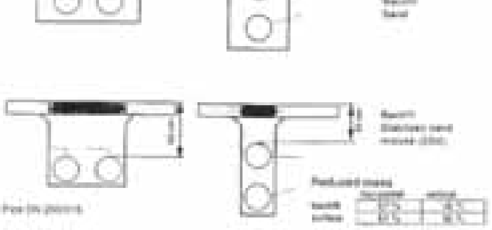


Fig. 5-19: Scheme to reduce construction-volumes by use of SSM

Fig. 5-18 (on the right): Floating prevention dams

Today, two safety-measures are recommended with liquid backfilling of pipes. Muff joints often extend are little to the outside of the pipe and, therefore, might be put under extra forces by axial movements of the pipe in SSM. Because of this muff joints should be wrapped into rock-shielding-sheets, according to Fig. 5-17. Moreover, caution must be taken when filling the trench with liquid assuming that the pipes are fixed in position thus preventing them from floating. This measure is implemented the easiest by fixing the pipe with small amounts of highly viscous SSM in equal distances of about 6 m. By this it is also guarantied that the later added low viscosity SSM does not flow along the entire trench uncontrolled. Fig. 5-18 depicts this kind of construction. The pipe is initially fixed with thick SSM and then each compartment is filled up with thinner SSM. This way, the trench can be filled up to the top in one step avoiding the material to rinse along the trench and harden layerwise.

By liquid backfilling of the trench the handled masses are reduced remarkably. This is shown in Fig. 5-19 at the example of a DN 200 pipe. The savings are even greater with vertically laid pipes than with horizontal laid ones. With horizontal laying the excavated masses reduce to 64% and with vertical laying to 46% of the values for a sand bedding. The same reduction applies for the masses of street restoration.

The cost savings by SSM depend on the price of the mixture. The following cost / benefit table shall give further insight:

Costs	Benefits
• Production of the SSM (base material, additives, mixing, ...) • Installation in the trench	• Less excavated volume due to smaller trench • Lower cost of transport and landfill • Less virgin materials • Possibly no cut-back at trench sides

In Germany, the break-even is at about 50 US $\$/m^3$ for SSM. This price is well met by competition.

Moreover, it is known by a rule of thumb what savings are possible if the liquid is used throughout the trench up to the bottom surface of the bituminous layer. By saving cut-backs and restoration-work of the street surface the overall pipe installation costs may be reduced by 15%.

5.5 Stabilized Sand Mixtures with Coarse Grains

The advantages of liquid backfilling as are described in section 5.4 require the production of SSM which is best if made from the excavated material. The costs can be reduced further if coarse grain can be used. This was the reason for tests with coarse grained backfill at the SP-Swedish National Testing and Research Institute, Göteborg. These tests were designed to build the basis for further investigations in this field. The experiments gave promising results that might, in the long term, open the way for considerable savings.

The results of the friction measurements have already been given in Table 5-15 together with the values for the other backfill materials. Here, it has to be added that coarse grains impose the danger of damage to the pipe casing. However, only qualitative answers may be given at the time.

Coarse lumps in the bedding material are primarily dangerous in sections where the pipe movements are large. Here, difference must be made between axial and radial movements. With hydraulic backfill, large stones are encapsulated by finer material thus shielding their edges off the casing thereby reducing the chance of lumped loads. The pipe is shifted in a channel-like space with smooth walls and won't be affected, see Appendix 2 Fig. 5.3, 5.4. However, extending elements, like muffs-joints or service connections need to be saved separately, see Fig. 5-17.

Also in the case of radial movements SSM's may have positive effects due to their smooth interfaces. However, if the radial movements are large one would apply expansion pads to avoid overstressing of the PUR foam.

Yet there is no doubt that knowledge is to scarce to define yield values for the specification of material. There is a long way of investigations to go before all expected advantages of hydraulic backfilling will come into effect.

6 Conclusions

Obviously, it is possible to achieve a decent quality of district heating pipes without utilizing high-quality materials for the bedding resp. the backfilling of the pipe. Moreover, costs may be saved while, at the same time, resources are conserved, transportation and landfill-volumes are reduced and obstructions by construction works are minimized.

These findings yield first suggestions for the reuse of former construction material in district heating pipe installation. More systematic investigations are necessary before further optimization of construction works becomes possible which would bring about even higher cut-backs in costs.

The owner of a pipe system is always aiming at low cost solutions thus installing the most cost-efficient materials as trench backfill. The least-cost alternative that is readily available is the excavated material. If it is not possible to store the overburden next to the trench it has to be removed leaving the backfill options with virgin sands – as commonly used in the past – recycled or landfilled material. The price will be decisive amongst these choices.

In the past, usually natural sands were required for installation in the pipe zone. If this requirement is lifted crushed, thus sharp-edged, material may be used assuming that it is less expensive. In Sweden, crushed material of corresponding fine grading is permitted equivalent to natural material. In other countries, for instance Germany / Austria, natural sands are still required [4]. The above presented results do not justify these requirements anymore.

The specifications of the materials used for pipe bedding are primarily governed by pipe-safety concerns. Thereby, it is necessary to distinguish whether the pipe is in the fully restrained zone – remaining fixed in the soil – or in the friction zone thus moving in axial direction. In addition to that, the pipe may shift radially at the tails of the friction zones or close to branches.

The radial displacements are either compensated by the sand-bedding or by plastic pads. If the sand-bed is used for compensation coarse grains may be dangerous due to lumped loads, the reader is referred to [12, Appendix 1]. For the case of SSM-bedding it is suggested to use expansion pads to avoid damages of the PU-foam.

6.1 Coarse Materials

The results of section 5.2 suggest that historic estimates of pipe damage by coarse grains might be too conservative. At least damages due to axial movements of smooth pipes remain negligible if the fraction of coarse grains is not too high. Even the radial pipe displacement of 10 cm in the coarse grained backfill did not destroy the casing although it had caused major indentations. Because of this the upper grain size was limited to 20 mm by the Swedish regulation for pipe – installation.

If the suggestions of the investigators to allow 50 mm stones in the backfill is implemented in practical construction the overburden could be utilized more frequently as fill for the pipe zone. Possibly, the permission of 10 cm grains will be successful when optimizing the mix of grain sizes; then the effort for possible sieving operation could be reduced.

Savings result if the overburden can stay at the construction site. If moving of the overburden is unavoidable savings seem almost impossible since price differences between substitute materials are rather small. Supplier prices differ only by nuances between virgin and recycled material. This is probably due to the acceptance charge for demolished construction material being such that prices after recycling match those for natural materials and, thus, remain competitive.

Two important questions are obvious today which need to answered before coarse grained, mechanical compacted material may be used to greater extent: How severe are muffs or other parts endangered by stone-containing material? Possible safety measures (stone-shielding sheet) shall be optimized. And secondly, how does coarse backfill affect the pipe long-term?

6.2 Hydraulic Compaction by Washing-in

Washing-in the backfill with water is the easiest way of compaction. Under favorable conditions a compaction-density is obtained that is just slightly below the required value for road construction. Washing-in is a really cheap and easy method. It offers remarkable advantages (narrow trench, quick construction works) without the necessity to process the backfill with binding and other additives as in the case of SSM. It looks like it is possible to wash-in the backfill more often than some years ago. In the area of reduced loads as sidewalks or bicycle-lanes washing-in is possible without inadmissible settling effects. Also, there is the option to compact further by additional mechanical techniques. Doing this, the trench could be filled and pre-compacted by washing-in. During a second step vibration compaction could yield the required final density.

6.3 Hydraulic Compaction with Binders

Today, pipe-trenches may be effectively backfilled by hydraulic compaction by tuning the filling material towards a liquid and mixing it with binders. Further improvements of this method seem possible. Several processing methods for the creation of SSM are available. They can be customized according to the specific location when needed.

The major economic advantage with hydraulic backfilling up to the bottom surface of the bituminous layer results from the fallen necessity to enter the trench. Thereby, no extra work-space for compaction workers needs to be provided enabling to keep the trench narrower by 20 cm. The excavated volume as well as the road surface to be restored are reduced by about 20%. Besides, situations exist where the trench support can be avoided, too. Hydraulic backfilling turns out to be especially effective for situations of vertically arranged pipes. Additionally, hydraulic backfilling accelerates construction works. This also yields further savings.

Experiences were made in former tests and applications:

1. The SSM does harden, not to form a solid block but rather a sand-like material. This is essential for pipe-bedding; furthermore, the material can be easily removed (e.g. by spate).

2. The hardening time can be adjusted such that quick proceeding of road construction is possible, e.g. after a 6 hour waiting period.

3. SSM may be made almost exclusively from excavated soil, for instance 95% by volume. On the other hand there are hydraulic backfills purely made from virgin materials. Even the utilization of these might be economically favorable.

4. The hydraulic backfilling with SSM seems to act in favor of coarse grains if enough fine grains are mixed-in also. Coarse grains are encapsulated by fines and fixed in their location such that the pipes are contained in a smooth-surfaced environment. Especially, this is the outcome of the tests at SP Provning Forskning, Göteborg, Sweden, as may be studied in Appendix 2, Fig. 5.1; 5.2; 5.3; 5.4.

5. The friction forces of pipes with PE-casing in SSM are higher than in sand-bedding. However, there are considerable uncertainties about the effects of installation and operation conditions. Mostly, layout calculations are based on the data for sand – bedding. Nevertheless, a 30% increased friction may be assumed already. Further uncertainties still exist about the long term behavior of friction. It is absolutely necessary to gain long-term experiences to avoid trouble with long-term displacements of the pipe.

The hydraulic backfilling of the pipe offers in excess to the current savings further potential for development. If the SSM is licensed as frost-resisting road construction material it can be utilized for filling up the trench up to the bottom surface of the bituminous layer. Thereby, the expensive cut-backs at both sides of the trench would be unnecessary. Even today, this technique is approved by some road construction authorities.

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Appendices

Appendix 1: Molin, J.; Bergström, G.; Nilsson, S.
Laying of District Heating Pipes Using Existing Soil Material, Excerpt of [12] in English

Appendix 2: Nilsson, S.
Testing of Coarse Grained Hydraulic Backfill Material, SP Swedish National Testing and Research Institute, Göteborg - Sweden

Appendix 1:

LAYING OF DISTRICT HEATING PIPES USING EXISTING SOIL MATERIAL

Jan Molin, VBB
Gunnar Bergström, SP
Stefan Nilsson, SP

Summary

Aim

The aim of this project was to find if it is possible to use existing soil material as backfill around district heating pipes designed according to EN 253 [1], with PUR insulation and PE casing pipes. If it were possible to use material of larger particle size than permitted at present, existing excavated soil could be used as backfill material. This would in many cases considerably reduce the cost of pipe laying. The investigations therefore concentrated on backfilling with coarse grained material.

The project comprised an analytical and an experimental part. In the analysis, a study was made of the economic conditions needed for cost savings, the environmental consequences, and the magnitudes of the loads transmitted from the backfill to the district heating pipe. In the experimental part, deformations and damage to 18 district heating pipes of DN 65/160, laid in 3 different types of backfill material and subjected to traffic load, were studied. One of the materials complies reasonably well with the existing Pipe Laying Specifications of the Swedish District Heating Association [2], while the other two are considerably coarser fractions, with cobbles of up to 100 mm side length. In the tests, the movements which may occur in a pipe system due to temperature alternations were simulated by repeated axial displacements.

Economy

The economic analysis shows that the cost of pipe laying in parks and natural ground could be considerably reduced if excavated soil could be used as backfill, due to savings in both materials and transport. The reduction in cost is not as evident when pipes are laid in city centre areas. Owing to lack of space, material cannot be stockpiled along the pipe trench, and extensive haulage of material to and from the site is therefore hard to avoid.

Apart from the economic savings when excavated soil is reused, there are also positive environmental effects, since there is less encroachment on nature due to the reduced need for borrow pits and transport, less use of natural resources and less environmentally harmful discharge.

Pipes

Field trials indicate that, at least in the short term, backfilling with coarser grained material than is permitted at present does not increase the risk of damage to the pipes. Some doubts however remain concerning the resistance of the casing pipe to long term indentation by stones. In addition, it is not clear how the joints in the pipe are affected by the coarser backfill material during displacements of the pipe.

Laboratory measurements have shown that the compressive strength of the PUR material is normally twice as large in the axial as in the tangential direction, with the radial strength as the average. This shows that there is a large measure of anisotropy in the foam, which means that the relationship between compressive strength and density is not as unambiguous as has normally been assumed.

Pipe foundation

The foundation for the pipe is a bedding layer of sand or gravel of 20 mm maximum particle size. If the bedding layer also is to serve as drainage layer, not more than 2% of the particles must be smaller than 2 mm.

Backfill

In addition to protecting the casing pipe and joints against mechanical damage, the backfill must also provide sufficient friction along the casing pipe. In order that satisfactory long term function of the pipe may be ensured in both these respects, it is recommended that backfill up to at least 200 mm above the crown of the pipe should be of material of maximum 20 mm particle size. Isolated particles of 50 mm maximum size may occur, but not adjacent to casing pipe joints, bends surrounded by backfill and branch connections, unless these have been given special mechanical protection or shown to have adequate strength. The backfill is compacted in the normal way in accordance with Table C/5 of MarkAMA 83 [3] (General Material and Workmanship Specifications for Earthworks).

Backfilling above 200 mm from the crown of the pipe is to be carried out as specified in Section C2.5 of MarkAMA 83 [3], or in a way specified by the authority responsible for the surface.

Swedish recommendations [2] assume an effective coefficient of friction of 0.4 in calculating friction forces and friction lengths. In calculating movements at the free end of the pipe, it must however be borne in mind that the coefficient of friction may have a low value, and it is normally assumed that its value may drop to zero. When the pipe is laid so that its movement is *restrained by friction* exerted by the backfill, the maximum spacing of movement absorbing elements should be equal to twice the friction length. For this method of laying, backfill of low friction such as silt and clay can be used without the design movements and forces in the pipe being exceeded. When the pipe is laid so that its movement is *prevented by friction* exerted by the backfill, on the other hand, the distance between movement absorbing elements is greater than twice the friction length, and backfilling with fine grained soil which has low friction against the pipe results in movements being appreciably greater than assumed in design. Nor can fine grained material be compacted in practice, and considerable settlement therefore might occur above the pipe, for instance in a street surfacing. However, backfilling with fine grained soil does not cause mechanical damage to the casing pipe, and can therefore be used on sections where no friction forces are required or where there is no risk of damage due to settlement.

Backfilling around bends, when the bend is enclosed in a box or surrounded by insulation slabs and covered with geotextile, can be carried out in accordance with the above specifications. Bends constructed without either a box or insulation slabs can be backfilled with the material specified above, of maximum 20 mm particle size, if the recommendations according to [7] are complied with. This means that the backfill is not compacted over a distance equal to 10 x DN on each side of the bend. In rock or firm soil (hard moraine), the distance between the pipe and the wall of the pipe trench should not be less than twice the outside diameter of the pipe over a distance equal to ten times the outside pipe diameter, measured from the centre of the bend.

As regards the requirements for backfilling around branch connections, neither this investigation nor the recent investigation into bends laid without a box or insulation slabs [7] has dealt with this question. There are thus no new investigation results that warrant an alteration of present practice on this point. The existing pipe laying recommendations [2] refer only to the alternative with a box or insulation slabs (Diagram 5). Obviously, however, branch connections can be laid directly in the ground without a box if they are on a fixed section of the pipe or if movements in this are small. In such cases the requirements for the pipe trench and backfilling should be the same as when a bend is laid in firm soil or rock, i.e. the trench is to be widened so that, for a branch connection, the distance between the pipe and the wall of the trench is at least 2 x DN over a distance of 10 x DN, and backfill, of material of max. 20 mm particle size, is not to be compacted .

Contents

1 Introduction

The current recommendation regarding the laying of district heating pipes is that the pipe trench should be backfilled with gravel of 8 mm maximum size. The intention in using fine grained backfill material is to ensure that the pipe is not subjected to mechanical overloading due to earth pressure or traffic loads, and that the thermal movements which arise due to variations in pipe temperature do not damage the pipe or pipe joints. Experiences gained from pipes backfilled with the prescribed material give no reason to doubt that the current pipe laying instructions result in satisfactory laying. There have however been discussions lately whether it would be possible to achieve satisfactory laying when the material excavated from the trench is used as backfill, with larger stones removed by sieving if necessary.

There are both economic and environmental advantages in using existing material as backfill. Naturally occurring gravel and sand are limited resources and their price may therefore be expected to rise. Since natural materials are a finite resource, it is likely that restrictions on the extraction of such materials will progressively increase in future. Alternative materials and reuse of materials will be specified to an increasing extent. Extraction of natural materials such as sand and gravel will also be limited in order to conserve the natural environment. Increased reuse of excavated soil as backfill in pipe trenches will be in line with ongoing endeavours to reduce encroachment on gravel eskers and other material sources as much as possible. If excavated soil were reused on the site, there would be less need for material transport and the environmentally harmful exhaust emissions by vehicles would be reduced. These are mostly hydrocarbons, oxides of nitrogen and carbon dioxide. There are also other positive effects such as less traffic noise and greater road safety. To an increasing extent, crushed gravel will be the available replacement material. Regardless of whether natural sand or crushed gravel is used as backfill, the present laying method requires a considerable amount of transport. Removal of the excavated soil and the supply of sand and gravel to the site constitute a not inconsiderable proportion of construction costs. If the excavated soil could instead be used as backfill, this would therefore be an advantage from the economic standpoint.

The reason for the present restrictive pipe laying regulations is to prevent damage which may occur during the service life of the district heating pipe. If the backfill material used contained larger stones, unfortunately placed sharp stones could cause considerable local deformations in the casing pipe and at joints in this. The casing pipe could also be scratched and torn during temperature movements in the pipe system.

The project has comprised two parts. In the analytical part the technical and economic aspects of using existing material as backfill were examined and evaluated, while in the experimental part a field test was carried out and evaluated, comprising a number of different district heating pipes backfilled with material of coarser grain size than that permitted in the current pipe laying regulations. The report summarises both these parts.

2 Aim and arangement of the project

2.1 Aim

The overriding aim of the project was to find whether it is possible to reduce the total construction cost for underground district heating pipes. By fully or partly replacing the normally specified gravel with existing excavated soil, considerable savings could be made in many cases. Even if the pipe would have to be reinforced in some respect, the total cost might still be lower.

It is known that the current requirements regarding the thickness of the casing pipe (laid down in the European Standard EN 253 [1]) were mainly specified in order to restrict expansion when the polyurethane insulation is foamed during the manufacturing process. It is also evident that the now available PEH materials, in thicknesses in accordance with the present EN 253, are generally so resistant that damage due to normal handling or loading is rare.

The project studied the effect on straight sections of district heating pipes due to backfilling with some different types of non-standard materials. The intention of the investigation was to find whether it is possible to use, or modify, the traditional district heating pipe with PUR insulation and a polyethylene casing pipe when existing soil is used as the backfill material, and to draw up specifications for such backfill material.

2.2 Arrangement

The project was performed in two parts, an analytical part and an experimental part.

In the first part, a literature search was made and calculation methods, experiences and previous experimental results were examined. The results of this work were partly used as the basis in choosing loading combinations in the field tests and for the additional calculations and experiments which were made.

In the second part of the project a comprehensive field test was made and evaluated. 18 district heating pipes of 12 m length were backfilled with three different materials and were subjected during an experimental period of 2 - 5 months to both a static earth load and repeated traffic loads. Finally, a number of the pipes were subjected to fifty cycles of axial displacement, intended to simulate the temperature movements in a district heating pipeline.

The materials used for the bedding layer and backfill were 0-100 mm crushed material, 0-100 mm natural gravel, and 0-8 mm crushed material. The two coarser materials were chosen to represent extreme cases in using existing soil as backfill. The third material is in close agreement with the standard material and was used as reference.

3 Methods of construction

3.1 General

The choice of construction method is influenced by the environment in which the pipe works are to be carried out. In an urban environment the space is often greatly restricted and it is important that the ground should be reinstated quickly and effectively. In parks and natural ground the surfaces are relatively easy to get to and there is less need for early reinstatement.

This report studies construction methods in three environment types: city centre, suburban area and park ground (outside a town).

3.2 City centre

Space in city centres is often constricted, and many players must agree regarding the space available. This means that pipe works must encroach as little as possible on existing spaces and must in addition be carried out quickly and effectively. The existing surfacing must be reinstated as soon as possible after the works are finished. No settlements in the ground surface are usually accepted. An example of a pipe trench section in a city centre area is shown in *Figure 3.1*.

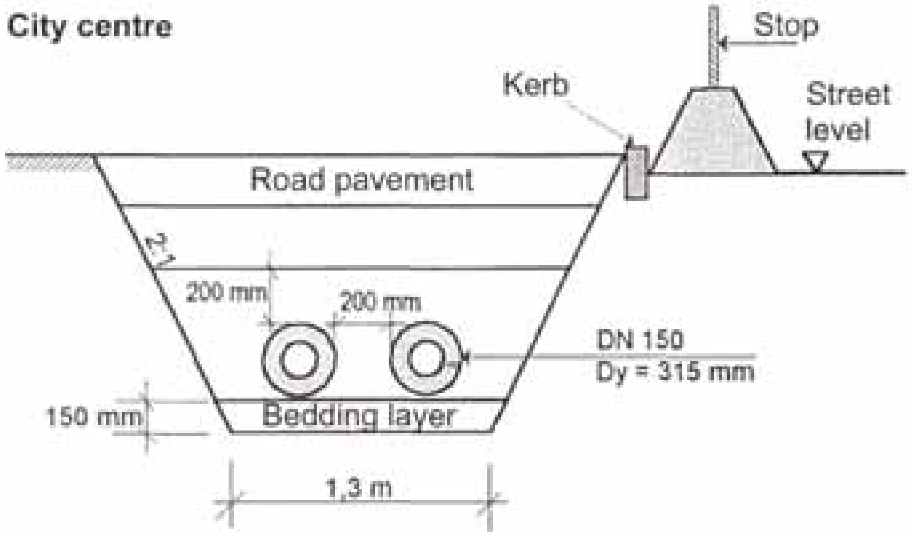


Figure 3.1 Example of pipe trench section in city centre. Pipe dimension DN 150

In order that backfilling with existing material may be carried out effectively, it is necessary for excavated soil to be stockpiled near the excavation. In a city centre environment it is not normally possible to pile up the excavated soil near the trench, but it must be removed. This also means that all fill material must be carried to the pipe trench from borrow pits.

In order to make substantial changes to pipe laying methods in a city centre environment, it is necessary to make radical modifications to current technology. Such a modification would be to develop the technique for jointing the service and casing pipes and to shorten the time taken by these operations. If this could be done at approximately the same rate as excavation and backfilling, it would be possible to reduce pipe laying time considerably. Excavation and backfilling could then be made in a continuous operation without intermediate storage of the excavated material, provided of course that this is suitable for use as backfill. The pipe trench would then have to be kept open for a distance not exceeding two pipe lengths, and the whole laying procedure could be made more efficient.

This laying method presupposes that the excavated material is a friction soil since this can be compacted. Clayey soil cannot be used owing to the difficulties of compacting this material. Settlements in the ground surface cannot be avoided, which would not be acceptable in this case.

3.3 Suburban areas

In a suburban environment there is generally more room than in the city centre, which means that it is easier to find space near the pipe trench where the excavated material can be stockpiled. Since traffic mobility requirements are less stringent in such areas, part of the street can for instance be closed and used for stockpiling the excavated material. See *Figure 3.2*.

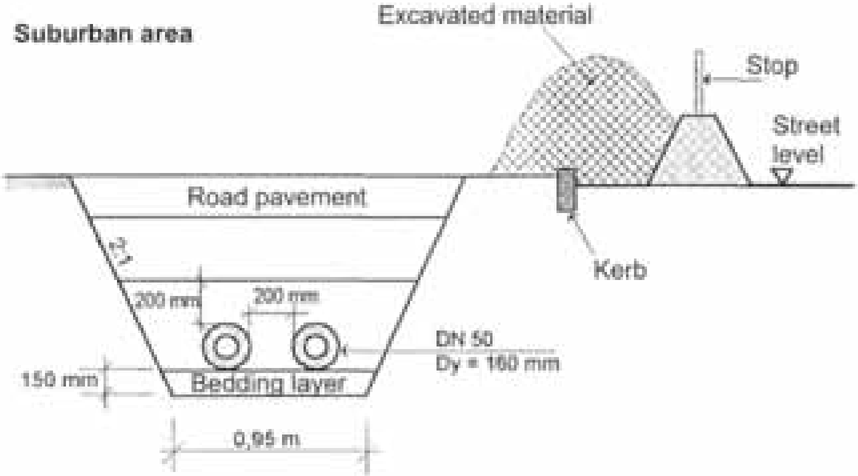


Figure 3.2 Example of pipe trench section in suburban area, dimension DN 50

In suburban areas the excavation can usually be kept open over a longer distance than in the city centre, and this makes for more rational pipe laying. If the space at the side of the pipe trench so allows, the pipes can be welded together to lengths of about 50 m and jointed on the ground surface before the trench is dug. The pipes are then lifted into the trench. Welding and jointing can in this way be done considerably faster and more rationally than down in a constricted pipe trench. And if the existing excavated material can also be used as backfill, further time can be saved.

In suburban areas some settlement of the ground surface can also sometimes be tolerated, especially if surfacing can be laid a year or so after other earthworks and surfacing works are finished. This means that the backfill material could be subject to less stringent requirements than in city centre sites.

3.4 Parks and natural ground

In parks and natural ground appreciable economic gains and time savings can be made if the existing excavated material can be stockpiled inside the working area and reused. Apart from the reduction in transport costs, there are also secondary positive effects. There is less need, or no need at all, to construct new transport routes for heavy vehicles and to fell trees and clear the ground. In these areas there is usually no difficulty in finding suitable sites for stockpiling excavated soil near the pipe trench. Usually there is also room to weld together and joint long lengths of pipe on the ground surface before the pipe trench is dug, and to effectivise pipe works in this way. The section of the pipe trench can for instance be as in *Figure 3.3*.

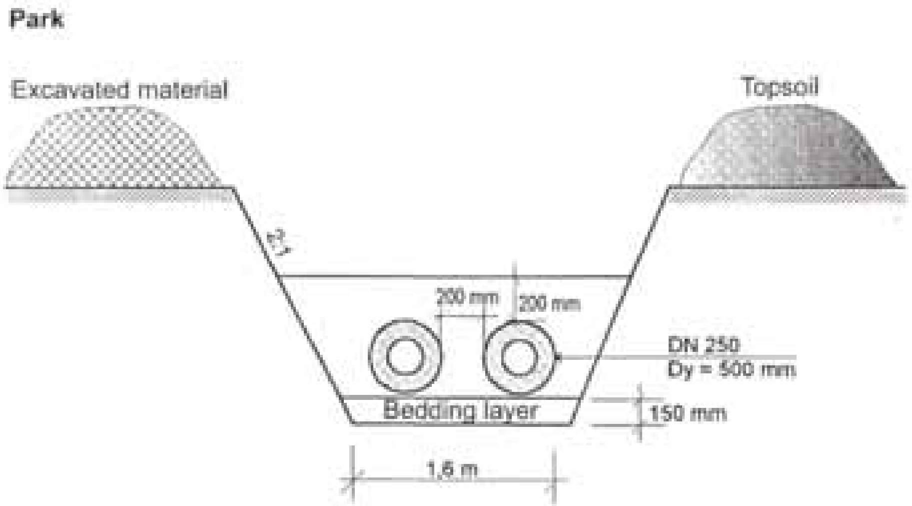


Figure 3.3 Example of pipe trench section in a park, dimension DN 250

4 Economy

4.1 General

The following discussion is based on Swedish conditions regarding the cost of buying and removing excavated soil etc.

The total construction cost of a district heating pipeline varies considerably depending on where the pipe is laid. According to [4], the cost of the most expensive pipe laying operation in a city centre environment is 10 times as high, or higher than, the cost of work in the least expensive natural ground.

Figure 4.1 - *Figure 4.2* set out the costs of pipe laying in a city centre and park ground respectively according to [4]. It is seen that the proportion of the total cost attributable to earthworks and construction works is high in the case of small pipe dimensions but smaller in the case of larger pipes.

In the following, only the possible savings due to the use of backfill subject to less stringent specifications have been considered. As far as the bedding layer is concerned, it has been assumed that materials will be subject to the same requirements as at present in view of the high risk of damage when the pipe is laid on a stony or uneven and hard bed. However, in the case where the bottom of the excavation is a soft soil free of stones, the bedding layer can be replaced by a blinding course of sand irrespective of the type of backfill material used. The other fill material in the pipe trench is assumed to be the same in all the alternatives, and its cost is therefore not taken into consideration in the economic comparisons.

The cost of buying fill material and removing excavated material varies steeply between different areas of Sweden. In the following calculations it is assumed that material from borrow pits costs SEK 130/m^3, and removal of excavated material ca SEK 60/m^3. These prices hold for the Malmö region in the south of Sweden in 1996.

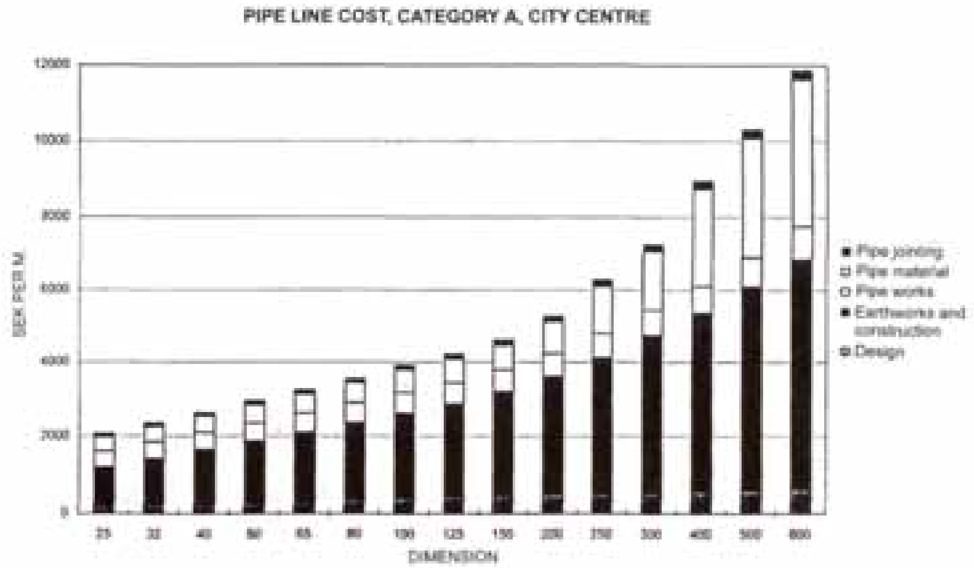


Figure 4.1 Pipe line costs in city centre according to [4]

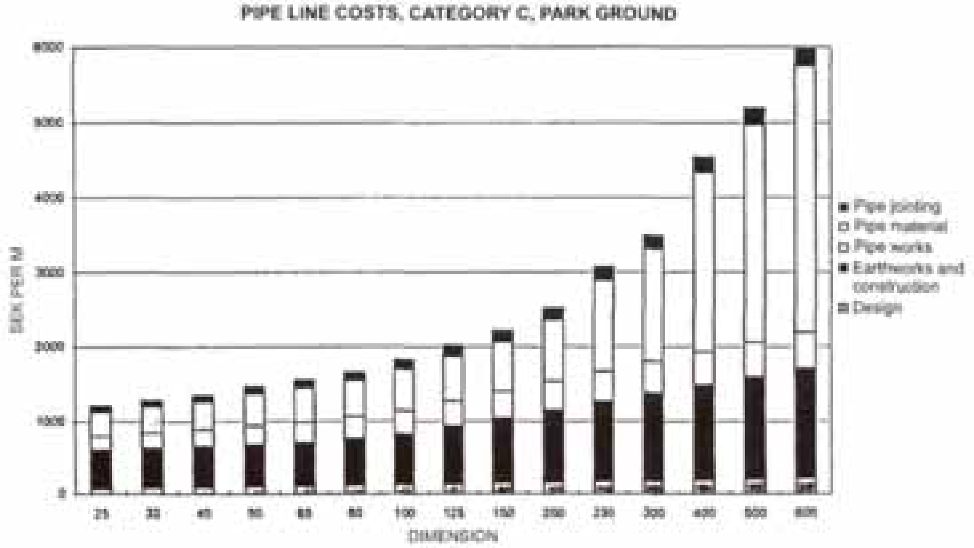


Figure 4.2 Pipe line costs in park ground according to [4]

4.2 City centre

Pipeline costs are highest in city centre areas. This is mainly due to the very high construction costs, primarily reinstatement works, precautions relating to existing services, and traffic control. According to [4], construction costs account for ca 60% of the total cost for the smaller sizes, and for ca 50% for the larger pipes.

According to *Figure 3.1*, a district heating pipe, DN150 and outside diameter 315 mm, is surrounded by ca 0.7 m^3 backfill per metre run. If the excavated material can be stockpiled near the pipe trench and if the existing material can be used as backfill, the saving in cost is ca SEK 130/metre run.

According to [4], the cost of earthworks and construction works for this example is ca SEK 2700/m. The total cost is thus ca SEK 4600/m of pipe. The use of existing material therefore reduces the cost by less than 5%. In the normal case it is however probably difficult to find room for the excavated material near the pipe trench. This necessitates transport and handling at an intermediate storage place, which further reduces the above saving.

4.3 Suburban areas

According to [4], the total cost of a district heating pipeline in suburban areas is ca 60% of the total cost of the same pipeline in a city centre environment. The main reason for the low cost is the reduction in construction costs.

A common dimension in suburban areas is DN50 and an outside diameter of 160 mm which requires ca 0.4 m^3 backfill per metre according to *Figure 3.2.* With the same reasoning as above, use of existing material results in a ca 9% reduction in construction costs (according to [4], ca SEK 900/m), provided that the material can be stockpiled near the pipe trench. See *Figure 4.3.*

4.4 Parks and natural ground

Costs in parks and natural ground are ca 10% lower than in suburban areas. The cost of earthworks and construction account for ca 45% of total costs for the smaller sizes and ca 35% for the larger sizes.

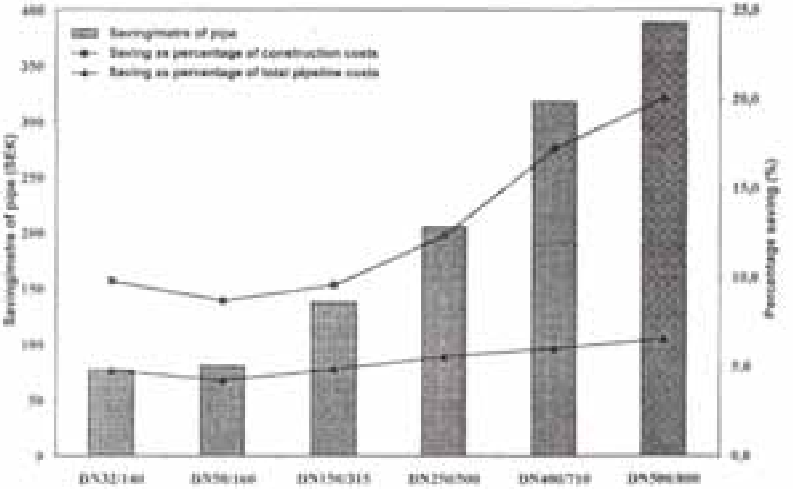


Figure 4.3 Savings in suburban areas and in parks

The pipe studied in parks and natural ground has the dimension DN250 and an outside diameter of 500 mm, requiring ca 1.0 m^3 backfill per metre run of pipe, as shown in *Figure 3.3.* In the same way as in the above example, use of existing material results in a ca 19% reduction in construction costs (ca SEK 1100/m according to [4]). See *Figure 4.3.* To this must be added the savings which can sometimes be made in other earthworks, for instance when there is no need to construct special haulage routes for heavy vehicles. This potential saving may be considerable in the individual case and result in a much larger saving than that above.

5 External loads

5.1 Earth pressure

The magnitude of vertical earth pressure on a buried pipe is governed by a number of factors. Two factors of great significance are the relationship between the stiffness of the pipe and the soil, and whether the pipe is laid in a trench or in an embankment. These conditions are illustrated below.

When the pipe is laid in a narrow trench, the loads acting on it are set out in *Figure 5.1*.

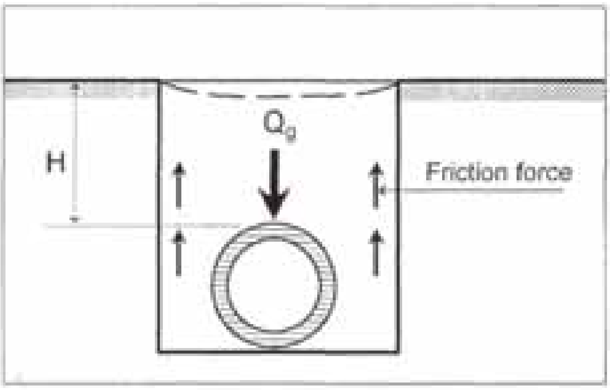


Figure 5.1 Loads acting on pipe in narrow trench

The conditions in a narrow trench are characterised by slight settlement of the backfill, resulting in upward friction forces along the walls of the trench which reduce the vertical load on the pipe. If the backfill at the side of the pipe is not compacted properly, most of the vertical load at the level of the crown of the pipe will be carried through arching action by the pipe if it is stiff. The load on the pipe can then be expressed as

$$Q_g = C_g \cdot \gamma \cdot B^2 \text{ kN/m} \qquad (5.1)$$

C_g = trench load factor
γ = density (ca 19 kN/m^3 for sand)
B = width of trench

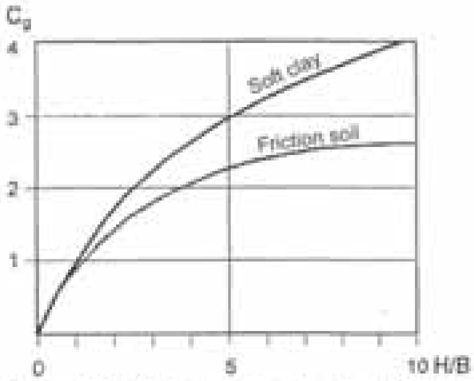


Figure 5.2 Pipe in trench. Load factor C_g. According to [5]

The value of the trench load factor C_g depends on the angle of internal friction of the backfill material and the coefficient of friction between the fill and the trench walls. The value of C_g for different fill materials is plotted in *Figure 5.2*, see [5]. The value of the load factor is greatest for clay and least when the backfill is a friction soil.

When the pipe is laid in an embankment, a stiff pipe is deformed less than the fill at the side of the pipe. The column of earth right above the pipe will therefore settle less than the surrounding fill, and will therefore be subject to downward vertical friction forces which increase the vertical load on the pipe. See *Figure 5.3*.

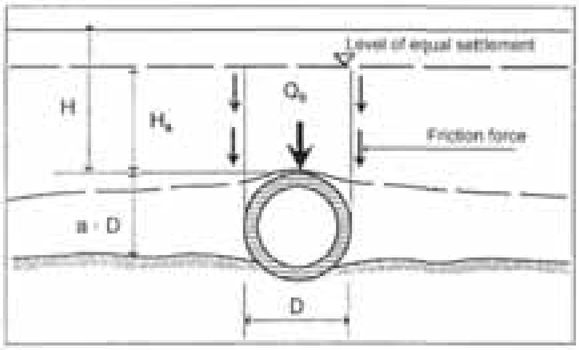


Figure 5.3 Pipe in fill

The load on a pipe laid in an embankment is to a great extent governed by the settlement conditions around the pipe; see [5]. These are defined by the coefficient of settlement r_{sd}:

$$r_{sd} = \frac{(\Delta m + \Delta j) - (\Delta l + \Delta f)}{\Delta m} \qquad (5.2)$$

where

Δm = consolidation of fill (depth a·D) at the side of the pipe
Δj = increase in settlement of subsoil at the side of the pipe
Δl = compression of pipe due to earth pressure
Δf = increase in settlement of subsoil under the pipe

For a stiff pipe, $\Delta l = 0$, and for a firm subsoil Δj is approximately equal to Δf. In such a case $r_{sd} = 1$. The value of r_{sd} may also be greater than 1, for instance if the pipe is laid on piles. The value of a for stiff pipes is usually assumed to be equal to 0.85 which represents the case when the pipe is effectively embedded along its bottom quarter circumference.

The greatest load on a pipe laid in an embankment occurs when the fill is a friction soil with a large angle of internal friction. The load on a pipe laid in an embankment can be written

$$Q_b = C_b \cdot \gamma \cdot D^2 \qquad (5.3)$$

where
C_b = embankment load factor
γ = density of fill, kN/m^3
D = outside diameter of pipe, m

Values of the embankment load factor C_b are plotted in *Figure 5.4* for a normal embankment on firm ground and for the case when the pipe is laid on piles in soft soil. The curve for $r_{sd} \cdot a = 0$ is also plotted; this represents the case when the crown of the pipe settles the same amount as the fill at the side of the pipe. The latter is usually the case for flexible pipes, e.g. buried drains of plastic materials.

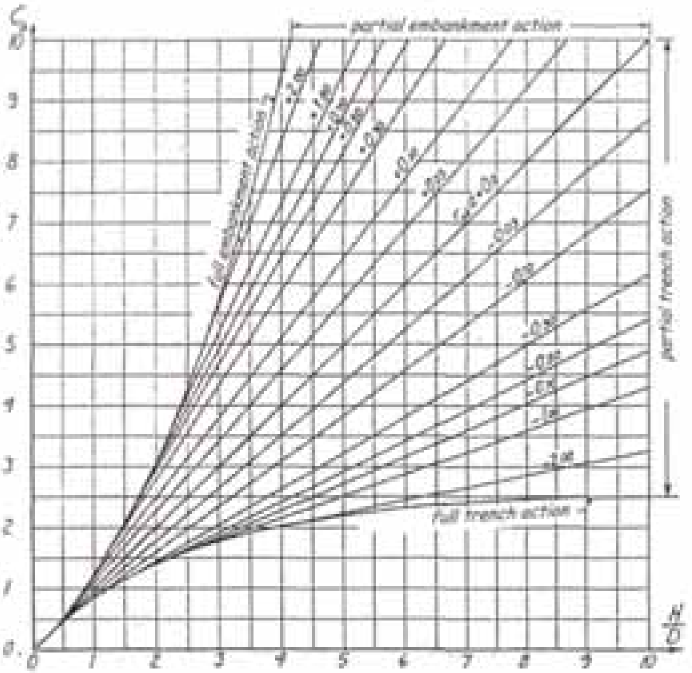


Figure 5.4 Embankment factor C_b for different values of $r_{sd} \cdot a$. According to [5]

The influence of pipe stiffness is also evident from *Figure 5.4*. The curve for $r_{sd} \cdot a = 0$ represents the case of a flexible pipe, i.e. when the crown of the pipe settles the same amount as the fill at the side of the pipe. The load on the pipe is then equal to the weight of the column of earth above the pipe.

For district heating pipes in accordance with to EN 253 [1], pipe stiffness is normally so high that loads should be calculated as for stiff pipes.

District heating pipelines usually consist of two pipes, and in most cases there are two parallel single pipes. A typical pipe trench for plastic pipes is shown in *Figure 5.5*.

The vertical load on the pipes in a trench as in *Figure 5.5* is calculated as for the embankment case.

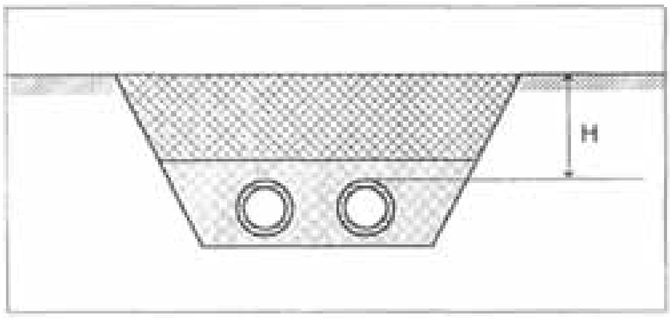


Figure 5.5 Pipe trench for two pipes

In practical design it is in most cases sufficient to calculate the vertical load due to the weight of earth for a stiff pipe in an embankment by the following approximate formula:

$$Q_b = 1.67 \cdot \gamma HD \text{ kN/m} \tag{5.4}$$

or

$$q_b = Q_b/D = 1.67 \cdot \gamma H \text{ kN/m}^2$$

Earth pressure at the sides of the pipe is usually lower than that on the crown and the bottom. The magnitude of horizontal earth pressure depends to a large extent on the stiffness of the pipe and the degree of compaction of the fill. For a stiff pipe in a narrow trench where the fill is poorly compacted, the horizontal pressure is practically nil while in an embankment fill it is approximately equal to the earth pressure at rest. The horizontal pressure Q_h on the pipe wall can be expressed as follows:

$$q_h = K \cdot q_o \tag{5.5}$$

where

K	= earth pressure coefficient
q_o	= vertical earth pressure at the centre of the pipe

For a stiff pipe the pressure q_o is somewhat lower than the overburden pressure, i.e. the weight of the earth above due to the "negative" arch action which arises in the earth above a stiff pipe. For a stiff pipe, the earth pressure coefficient K varies between 0.3 for active earth pressure and 0.5 for earth pressure at rest. If the vertical earth pressure is put equal to the overburden pressure at the crown of the pipe instead at the centre of the pipe, the horizontal pressure on the sides of the pipe can be calculated from

$$q_h = 0.5 \cdot \gamma H \text{ kN/m}^2 \tag{5.6}$$

For a district heating pipe the vertical foundation pressure at the bottom of the casing pipe is also appreciably dependent on embedment. If the pipe is laid on a hard flat surface without being packed underneath and without compaction of the surrounding fill, the angle of contact with the subsoil will be very small and the foundation pressure high. Since it is difficult to compact the backfill in the wedges between the bottom half of the pipe and the bottom of the trench, it is assumed for a stiff pipe that the contact angle is 90° when the pipe is packed underneath as specified in Mark AMA 83 (General Material and Workmanship Specifications for Earthworks) [3]. For a compressible pipe which is allowed to deform, the contact angle is approximately 180° when it is packed underneath with friction soil.

The distribution of vertical and horizontal earth pressure on a plastic district heating pipe is illustrated schematically in *Figure 5.6.*

If the bedding layer below the pipe is hard and uneven, pressures at the bottom of the pipe may locally be much higher than those shown in *Figure 5.6.* It is therefore essential that the pipe should be laid on a well levelled and soft bedding layer or a soft levelled trench bottom.

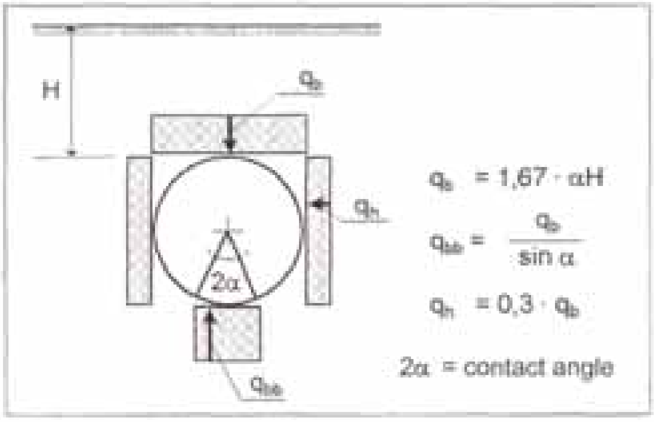


Figure 5.6 Schematic illustration of vertical and horizontal earth pressure on a stiff pipe

In district heating pipes with foamed PUR insulation the radial stiffness is normally greater than the vertical stiffness of the surrounding fill. Unless special measures are taken in packing underneath the pipe and compacting the backfill, it is recommended that the contact angle be put equal to 90°.

5.2 Traffic load

The effect of traffic load is described in [6]. The following is an extract from this publication.

In Sweden, the National Road Administration has set out in BRO 94 the load assumptions to be used in designing bridges. Four cases are given for traffic load, of which equivalent load types 1 and 2 are of interest in designing buried pipes.

Equivalent load type 1 consists of a load group with three axle loads each of 210 kN at distances of 1.5 and 6.0 m and a uniformly distributed load of 3 kN/m^2. Each axle load comprises two wheel loads at a distance of 2.0 m, and the wheel load is spread over a rectangular area measuring 0.2 x 0.6 m. The axle loads include a dynamic increment of 60%.

Equivalent load type 2 consists of one axle load of 260 kN spread over two wheel loads of 130 kN each at a distance of 2.0 m. The wheel loads are spread over the same rectangular area as in equivalent load type 1. The axle load in this case includes a dynamic increment of 75%.

It is assumed that dispersal of load in the ground is calculated according to Boussinesq's theory. The vertical pressure σ_{tr} at a depth H in the ground due to a point load on the surface is calculated as follows:

$$\sigma_{tr} = \frac{3P}{2\pi \cdot H^2} \cdot \cos^5 \beta \qquad (5.7)$$

where β is the angle between the vertical and a line connecting the point load and the point where the vertical pressure is calculated.

The size of the area over which the load acts (0.6 x 0.2 m) has a certain significance when the fill is of small depth.

Since stresses in the ground are dispersed in such a way that traffic load on a buried pipe has a non-uniform distribution, see *Figure 5.7*, the pipe is designed for a mean load q_m along a certain length L. For stiff pipes L is normally taken to be equal to 1.0 m. For compressible pipes with small depths of fill, this is however considered to give far too favourable a picture since load has not been dispersed to such an extent that averaging over 1 m can be considered justified. In this case, the mean load over a length L of the pipe is therefore calculated as follows:

$$L = \begin{cases} H \text{ for } H \leq 1.0 \text{ m} \\ 1.0 \text{ for } H > 1.0 \text{ m} \end{cases} \tag{5.8}$$

where H is the depth of fill.

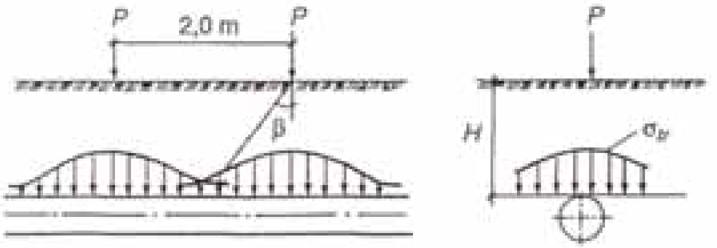
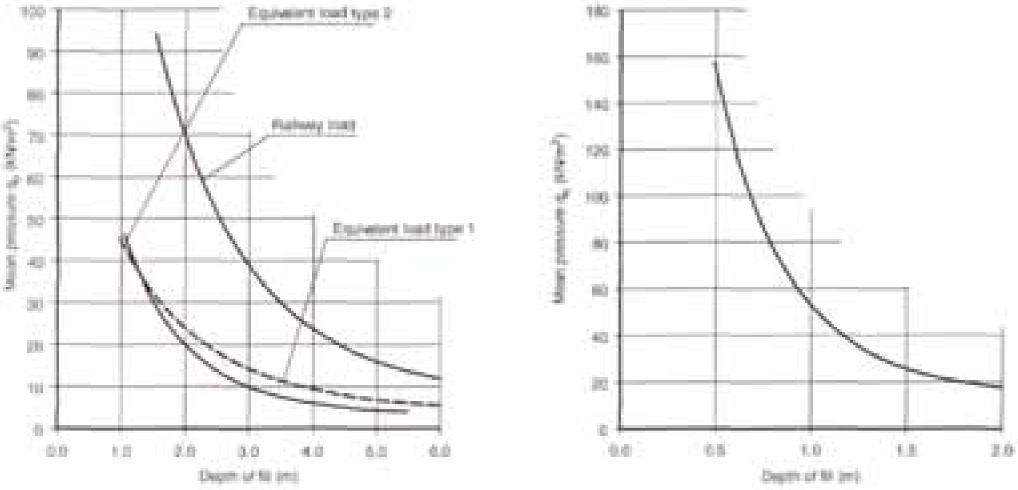


Figure 5.7 Distribution of vertical pressure due to traffic load on the pipe



(a) Equivalent loads type 1 and 2 and railway load. H > 1.0 m

(b) Equivalent load type 2. H ≤ 2.0 m

Figure 5.8 Mean pressure on buried pipe due to traffic load

Figure 5.8 shows the mean pressure q_{tr} for equivalent loads type 1 and type 2 for a pipe of 300 mm outside diameter. As will be seen in the figure, for small depths of fill it is type 2 that is the design criterion, and for large depths type 1.

The pipe diameter has little influence on the mean pressure when the depth of fill is large, but its influence increases as the depth decreases. The mean pressure set out in *Figure 5.8* can however be used in design for depths of fill of 1.0 m and upwards for pipes of 100 - 500 mm outside diameter since the error is limited to ca 10%. *Figure 5.8 (b)* sets out the calculated traffic load for depths of fill below 1.0 m for equivalent load type 2 which is then the design criterion. Account has also been taken of the fact that wheel loads are spread over a surface measuring 0.2 x 0.6 m which exerts an influence when depths of fill are small.

The equivalent loads include a dynamic increment. It is assumed that in soil the dynamic increment decreases linearly with depth, so that it is equal to zero at a depth of 6.0 m below ground level (VAV P43). The calculated mean pressures must therefore be multiplied by a reduction factor as follows:

Equivalent load type 1 $\alpha = (1.60 - H/10)/1.60$

Equivalent load type 2 $\alpha = (1.75 - H/8)/1.75$

where H = depth of fill

When a stiff pipe is placed in more compressible backfill, the pipe will give rise to a disturbance in stress distribution so that a pressure concentration occurs above the pipe. The calculated mean pressure at the level of the crown of the pipe is therefore multiplied in accordance with the recommendations in VAV P43 by a concentration factor (1+K) in order that the load on a completely stiff pipe may be obtained. The values of the factor K are as follows:

$$K=\begin{cases} 0.7\cdot\dfrac{H}{4.5D} & \text{for } \dfrac{H}{D} \le 4.5 \\ 0.7 & \text{for } \dfrac{H}{D} > 4.5 \end{cases} \tag{5.9}$$

The design traffic load on a stiff pipe can then be calculated as the product of the influencing factors:

$$Q_{tr} = \bar{q}_{tr} \cdot D \cdot \alpha(1+K) \quad \text{kN/m} \tag{5.10}$$

5.3 Transverse displacement of pipe in the horizontal plane

At and near bends, a district heating pipe surrounded by backfill undergoes transverse displacements in the horizontal plane due to temperature variations in the pipe. The magnitude of these movements is primarily dependent on the method of installation and the pipe dimension.

The results of field tests on two pipe sizes, DN40 and DN150, laid with a backfill of compacted and uncompacted sand, are set out in [7]. The pipes were subjected to mechanical sideways displacement.

Figure 5.9 sets out the measured and calculated horizontal earth pressures on the pipe wall for different displacements. It is evident that the measured earth pressures are in relatively good agreement with those calculated for compacted sand backfill, while they are about only half as large as those calculated for uncompacted backfill. The number of tests was however quite small, and it is therefore recommended in [7] that no far reaching conclusions should be drawn from these results for uncompacted backfill.

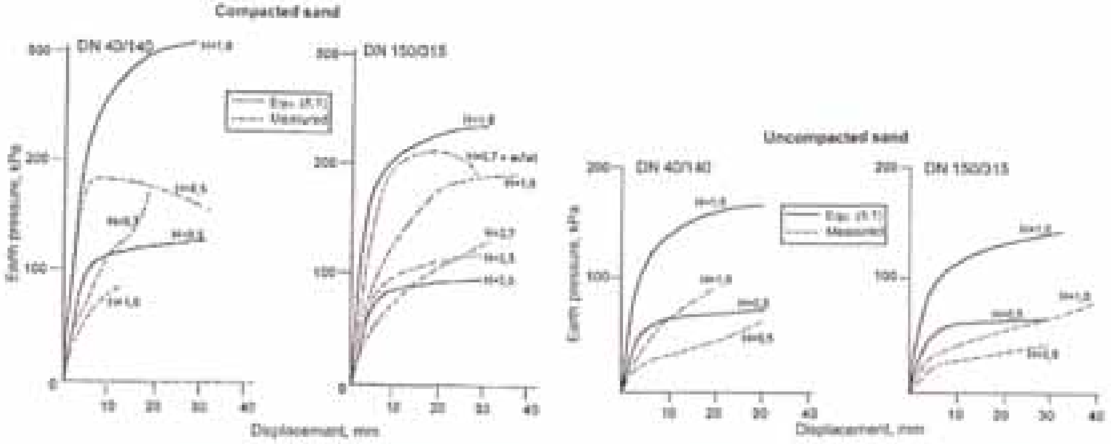


Figure 5.9 Calculated and measured horizontal earth pressures in loading tests in the field. [7]

5.4 Stones in contact with the pipe

The pipe laying instructions which are present applied for Swedish district heating pipes prescribe that backfill must consist of stone free friction material of 8 mm maximum particle size. This provides a favourable pressure distribution around the pipe and there are no high local point loads on the casing pipe. If the backfill contains stones or if the pipe is laid on a stony bedding layer, the casing pipe will be subjected to point loads of varying size.

The force exerted by the stone on the pipe wall may be assumed to be proportional to the earth pressure multiplied by the projected area of the stone perpendicular to the wall, provided that the stone is well embedded in homogeneous soil. The *contact pressure* between the stone and pipe wall is however dependent on the size of the contact area and can be calculated from the following expression:

$$q_{st} = \frac{A_1}{A_2} \cdot q \tag{5.11}$$

where

q_{st} = contact pressure at stone, kN/m^2
q = earth pressure, kN/m^2
A_1 = total projected stone area perpendicular to the pipe wall
A_2 = contact area between stone and pipe wall

The earth pressure q is the earth pressure acting on the stone. If it is in the fill next to the pipe wall, the earth pressure can be approximately calculated according to the method set out in the previous section concerning the effect of load due to earth pressure, traffic load and horizontal displacement of the pipe.

The earth pressure on the pipe varies as shown in the previous section. Because of this, the force exerted by a stone will vary depending on where in the fill it is situated. *Table 5.1* sets out approximate values of the force exerted by stones of assumed square surface situated in different positions around the pipe. It is assumed that the depth of fill above the crown of the pipe is 1.0 m and the pipe dimension is DN150/315. The fill at a bend in the pipe is assumed to be compacted and the sideways movement is assumed to be 10 mm.

Table 5.1 Calculated contact forces between stone and pipe

		Contact force, N		
Stone size (side length) mm	Position of stone	Earth	Earth + traffic	At a bend (without traffic)
8	Crown	2	7	2
	Side	1	3	13
	Bottom	3	8	3
50	Crown	83	272	83
	Side	25	120	500
	Bottom	118	308	118
100	Crown	330	1090	330
	Side	100	480	2000
	Bottom	470	1230	470

It is seen from *Table 5.1* that the contact force increases with increasing stone size. Broadly speaking, the increase is proportional to the area of the stone, i.e. proportional to the square of the side length.

It is evident from *Table 5.1* that the most dangerous position for a stone is at the bottom of the pipe, with the exception of that part of the pipe which is near a bend where a horizontal displacement takes place. The contact forces at the bottom of the pipe have been calculated with relatively favourable assumptions, i.e. that the pipe is positioned on a uniform bedding layer along its entire length and that the foundation pressure is distributed over the bottom quarter circumference of the pipe. Conditions are considerably more severe if the pipe is laid on a hard and uneven trench bottom or bedding layer since contact forces will be substantially higher locally.

It is also evident from *Table 5.1* that there is a risk that forces exerted by stones at the sides of the pipe will be high on those sections of the pipeline which undergo a horizontal displacement near a bend. The forces have been calculated on the assumption that the force is not influenced by the magnitude of deformation or indentation. In reality, contact with a stone will cause a local indentation in the pipe wall which will, in turn, give rise to a redistribution of the contact pressure, so that the pressure exerted on the stone decreases as the deformation increases. The forces and contact pressures set out in the table are thus extreme values applicabe to a completely stiff pipe wall. In a plastic district heating pipe, the deformations are so large that the contact pressures are probably lower than those above. The values in the table do however illustrate the significance of stone size with regard to contact pressure between pipe wall and stone.

6 Field tests

6.1 Test site

The tests were carried out at a rock crushing plant in Göteborg. The test site was made available by courtesy of the plant manager.

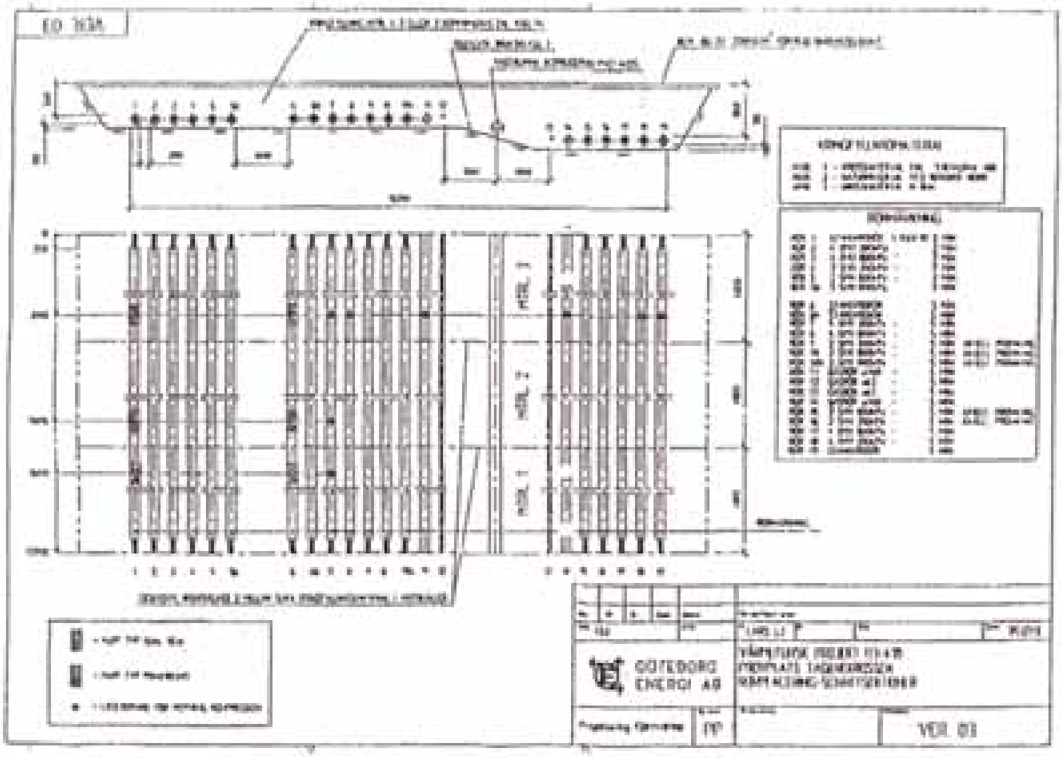


Figure 6.1 Sketch plan of test site. North is to the right

The site was convenient from several respects, mainly because of the intensive internal traffic with very heavy vehicles which was essential in order that the tests may be performed with the desired traffic loads. The close access to different types of gravel and stone material and the remote position of the site were also valuable considerations.

6.2 Scope

Seven different types of district heating pipe (a total of 18 pipes) made by Powerpipe AB were used in the test. All pipes comprised a steel service pipe of 76.1 mm diameter (DN65) and a polyethylene casing pipe of 160 mm nominal outside diameter. Most of the district heating pipes had casing pipes made from a traditional polyethylene material, Borealis HE2467 BL, but three pipes, 5b, 6b and 10b, had casing pipes made from a more recent 'bimodal' material, Borealis HE3470.

Based on the standard pipe in accordance with EN 253 [1], with a wall thickness of 3.0 mm and PUR strength of 500 kPa, the following types of district heating pipe were made:

Table 6.1 Types of district heating pipe

Pipe number (see *Figure 6.1*)	Nominal wall thickness, PE-pipe	Nominal compressive strength of PUR foam	PE material
2, 7, 18	4.0 mm	300 kPa	HE2467 BL
3, 8, 17	4.0 mm	800 kPa	HE2467 BL
4, 9, 16	2.5 mm	300 kPa	HE2467 BL
5, 10, 15	2.5 mm	800 kPa	HE2467 BL
1, 6, 19	3.0 mm	500 kPa	HE2467 BL
6b	3.0 mm	500 kPa	HE3470
5b, 10b	2.5 mm	800 kPa	HE3470

The actual values of casing pipe thickness and PUR insulation compressive strength were in many cases appreciably different from the nominal ones. Unless otherwise stated, the nominal values are used in the references to the different types of pipe (e.g. "2.5 mm/800 kPa").

For the test, a 12 m wide road pavement was constructed, divided in the longitudinal direction into three strips each of 4 m width, in which the following backfill materials were used:

- Material No 1: 0-100 mm crushed material
- Material No 2: 0-100 mm natural material
- Material No 3: 0-8 mm crushed material

Grading curves for the different materials are plotted in *Figure 6.2*.

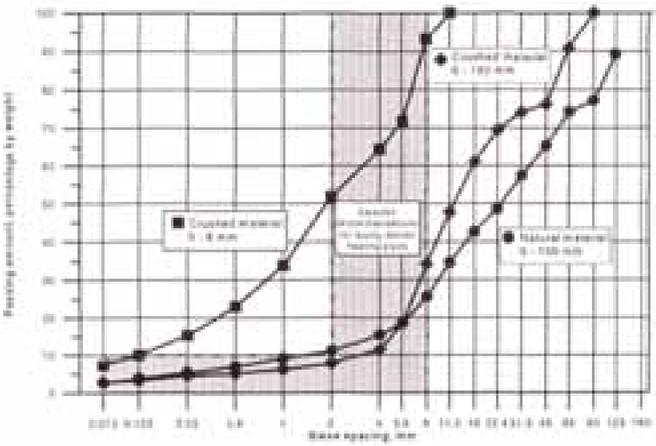


Figure 6.2 Grading curves for the backfill materials

The materials were chosen so as to cover even extreme backfill materials, and in the hope that clear indications would be received concerning the effect of the backfill material with regard to indentation and scratches on the polyethylene pipe.

In order to illustrate further the influence of the backfill, the pipes were laid at different depths. One group, pipes Nos 1 - 12, were laid at a depth of 0.6 m, and the other group, Nos 13 - 19, at a depth of 1.0 m.

Two of the district heating pipes were constructed with three joints each. The joints were positioned so that there was one joint in each backfill material. The jointed pipes are Nos 1 and 6, and the joint types are Dual Seal and Powerbond.

The following measurements were made:

- Continuous measurement of radial deformation of casing pipe and service pipe due to traffic load (passages by dumpers with 22 tonne axle load)
- A number of the buried pipes were subjected to axial displacement perpendicular to the longitudinal direction of the road by means of jacks in order to simulate thermal expansion movements which may arise in a district heating pipe system due to variations in hot water temperature.
- The casings of the pipes were examined for indentation damage due to earth and traffic load and scratching due to the axial displacements.
- The joints were subjected to leakage tests after the vehicle passage tests had finished.

6.3 Test procedure

Tests commenced in May 1996 and terminated in November 1996.

The fill over the pipes was paved with a ca 120 mm thick asphalt surfacing with elevated binder content in order to resist the loading imposed by the internal dumper traffic in the plant, vehicles with ca 220 kN axle loads. These vehicles are used inside the plant area mainly to haul crushed rock material. The asphalt surfacing was thicker than that used in a more normal street surfacing, but the traffic consisted of vehicles with considerably higher axle loads than those permitted on public roads. The effect of traffic on the pipes was to some extent attenuated by the thick surfacing, but it is nevertheless considered to have been more unfavourable than the loading to which district heating pipes are subjected on public roads.

In order to measure the compression of the PUR insulation, transducers were mounted inside the insulation between the service pipe and casing pipe.

The number of vehicle passages was recorded using a photocell, intended for traffic counts, mounted on one side of the carriageway. Compression of the district heating pipe was recorded with a datalogger once an hour during the test period.

After about 2 months and 2000 vehicle passages, pipes Nos 1 - 5b were dug up. The polyethylene pipes were visually examined on the site. The pipes were taken to the Mechanical Department of the Swedish National Testing and Research Institute in Göteborg where the pipes were subjected to further investigation with regard to e.g. shear strength at different positions along the pipes.

After 5 months and a total of ca 8000 vehicle passages, 5 of the pipes were subjected to the axial displacements described below. All pipes were then dug up. These were also subjected to an initial examination on the test site. The shear strength of these pipes was also determined. The joints in pipes Nos 1 and 6 were also subjected to leakage tests.

After the vehicle passage tests had been finished and before the pipes were dug up, pipes Nos 9, 10, 10b, 15 and 16 were subjected to axial displacements through the road pavement. This was performed using two jacks mounted at one end of the pipe. The force of reaction was provided by a frame of steel sections which was anchored in the rock. The axial movements were recorded with two positional transducers. One was mounted so that displacement of the steel pipe relative to the ground could be recorded. Shear in the PUR foam was checked by measuring, with the other transducer, the displacement of the polyethylene pipe in relation to the steel pipe. The force applied to the pipe was recorded by an electric pressure transducer connected to the jacks.

In order to gain an idea of the friction force contributed by the different backfill materials, pipes Nos 9 and 10 were subjected to displacement tests after some of the backfill had been removed. Displacement tests on pipe No 10 were made after backfill material No 1 had been removed, and on pipe No 9 after both backfill materials Nos 1 and 2 had been removed.

After the tests the pipes were dug up and examined for indentation and scratches.

6.4 Measurements

Radial deformation of the district heating pipes was measured with positional transducers mounted in the pipes. *Figure 6.3* shows an example of the development of compression over time.

There is very little compression of the pipe insulation: at most, ca 0.5 mm (PE 4 mm, PUR 300 kPa, pipe No 18). It is evident from the measurements that most of the compression occurs already when the backfill is compacted, and that, once traffic loading has been applied, the deformation relatively quickly reaches an approximately constant level.

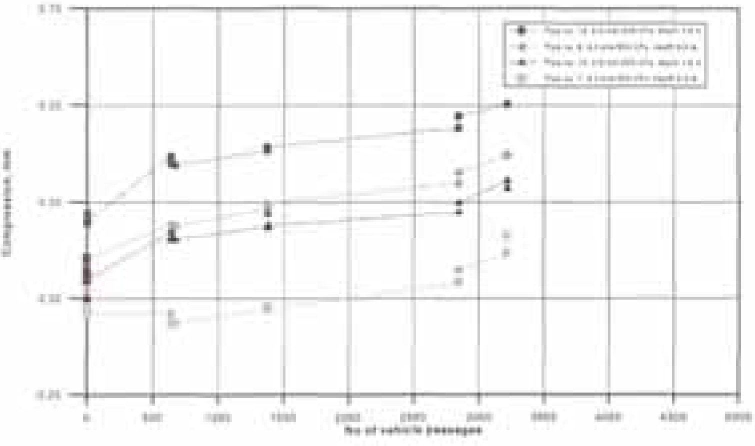


Figure 6.3 Radial compression at transducer placed in the 3 m position as a function of the number of vehicle passages

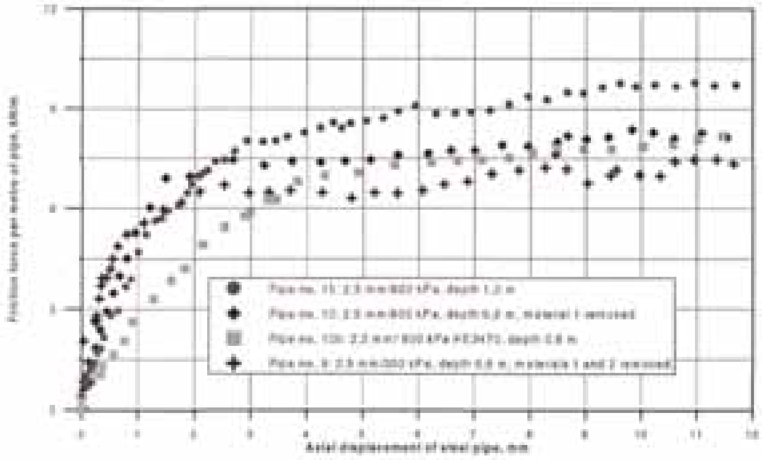


Figure 6.4 Applied axial force per metre of district heating pipe as a function of the axial movement of the steel pipe during the first displacement cycle

During the first displacement cycle the compressive and tensile forces were measured with a pressure transducer connected to the jacks. The positional transducers measured the displacement of the steel pipe relative to the ground, and the relative displacement between steel pipe and casing pipe. Examples of force-displacement curves are plotted in *Figure 6.4* above.

The force-displacement curve shows that the force increases until a certain "critical" deformation has been reached, after which displacement continues for only a small change in force.

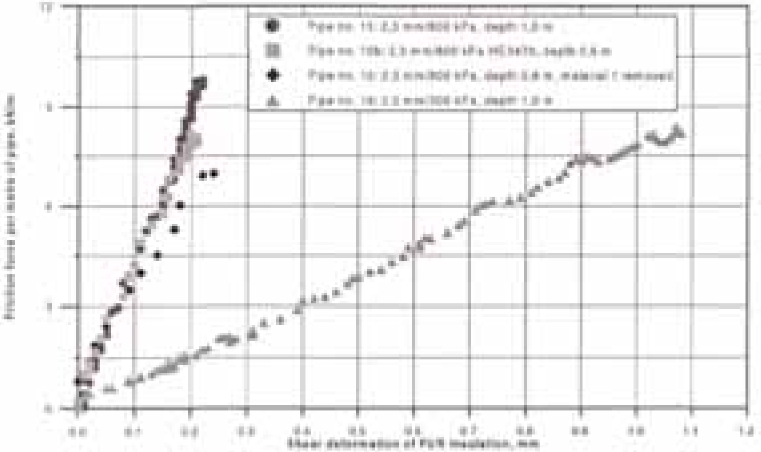


Figure 6.5 Applied axial force per metre of district heating pipe as a function of shear deformation in the PUR foam (difference between axial movements of steel pipe and casing pipe) during the first displacement cycle

Shear deformation in the PUR foam has a broadly linear relationship with the applied force. Approximate calculation of stresses in the PUR insulation near the service pipe gives $\tau_{PUR} = F/(2\pi rL) = 37.7$ kPa.

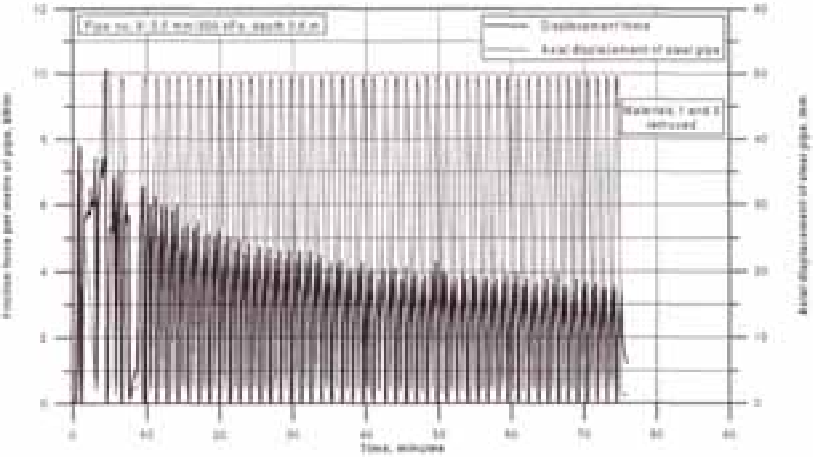


Figure 6.6 Applied axial force per metre of pipe and axial displacement of steel pipe as functions of time during alternating movements

The results of tests with alternating displacements show that the force required to produce a certain displacement decreases with the number of cycles (see *Figure 6.6*). This may be interpreted as the result of the progressive loosening, near the pipe, of the road pavement which had been consolidated by compaction and traffic load.

The coefficients of friction for the different backfill materials were calculated as the ratio of the applied axial displacement force to the calculated normal force on the surface of the casing pipe.

Measurements from the alternating displacements show that the force required to displace the pipe progressively decreases with the number of displacements. It is the final measured value of this force which is used in calculating the coefficients of friction.

The two tests used in the calculations were those in which one and two material types had been removed before the displacement tests were performed. The coefficient of friction was thus first calculated for material No 3 (displacement of pipe No 9, materials 1 and 2 removed). This coefficient was then used in determining the friction for material No 2 (displacement of pipe No 10, material No 1 removed), after which the coefficient of friction for material No 1 was calculated (displacement of pipe No 10b). The procedure adopted must be considered to be subject to a great measure of uncertainty but it can give an idea of the relationship between the friction properties of the different materials. It is evident that the natural material exerts the greatest restraint force, which may be due to the more extensive stone indentations found on the section of pipe in this material. See *Figure 8.1*.

The coefficients of friction were calculated according to both Andersson et al [8], see *Table 6.2*, and the procedure proposed in the present draft EN standard [9], see *Table 6.3*.

The calculated coefficients of friction are consistently higher than what is normally assumed in determining the friction lengths when pipelines are designed. As described above, the coefficients of friction are unreliable and cannot be used as the basis for changing the design procedure according to [8]. Reasons for the high values may be that the material used was abnormally coarse grained (materials Nos 2 and 3) and that the high traffic load probably gave rise to abnormally good compaction of the backfill. The results obtained are interesting and should be followed up by tests better designed for an investigation of the coefficients of friction alone.

Table 6.2 Coefficients of friction, calculated according to [8].

Material	Coefficent of friction
1: Crushed material, 0 - 8 mm	0.63
2: Natural material, 0 - 100 mm	1.00
3: Crushed material, 0 - 100 mm	0.71

Table 6.3 Coefficients of friction, calculated according to [9].

Material	Friktionskoefficient
1: Crushed material, 0 - 8 mm	0.73
2: Natural material, 0 - 100 mm	1.16
3: Crushed material, 0 - 100 mm	0.83

7 Changes in the properties of the pipes

7.1 Density and compressive strength

The initial properties of each type of district heating pipe were measured on unloaded reference pipes manufactured at the same time as those used in the field tests. All measurements were made at the Mechanical Department of the Swedish Testing and Research Institute, Göteborg.

The properties measured were the density of the PUR insulation, compressive strength in the radial direction, and axial shear strength. In order to obtain a proper understanding of how these properties change along the pipe, measurements were made at 10 sections spaced uniformly along half the length of the pipe. Measurements were concentrated on only one half of the pipe in view of the fact that during manufacture of the pipe the PUR foam is introduced through a hole at the midpoint of the pipe. There is therefore good reason to assume that the thermomechanical properties vary symmetricaly about the middle of the pipe. In view of the fact that measurements were made on three test specimens from each section, the total quantity of data provide a very good representation of how properties vary along the pipe. The way the core density and compressive strength vary along the pipe is set out for one of the pipes in *Figure 7.1*. The limiting requirements according to EN 253 [1] are also plotted.

In some of the reference pipes there is a large scatter in compressive strength for PUR foam of substantially the same density. Since this could not be explained by uncertainties in measurement, a special series of measurements were made to see whether anisotropy in the PUR foam might be the reason for this scatter. Such anisotropy may be thought to be a consequence of the formation of local orientations in cell structure during the foaming process. Measurements concentrated on the compressive strength of the material which was determined in three mutually perpendicular directions, radially, tangentially and axially. The tests were made pipes Nos 1-5b.

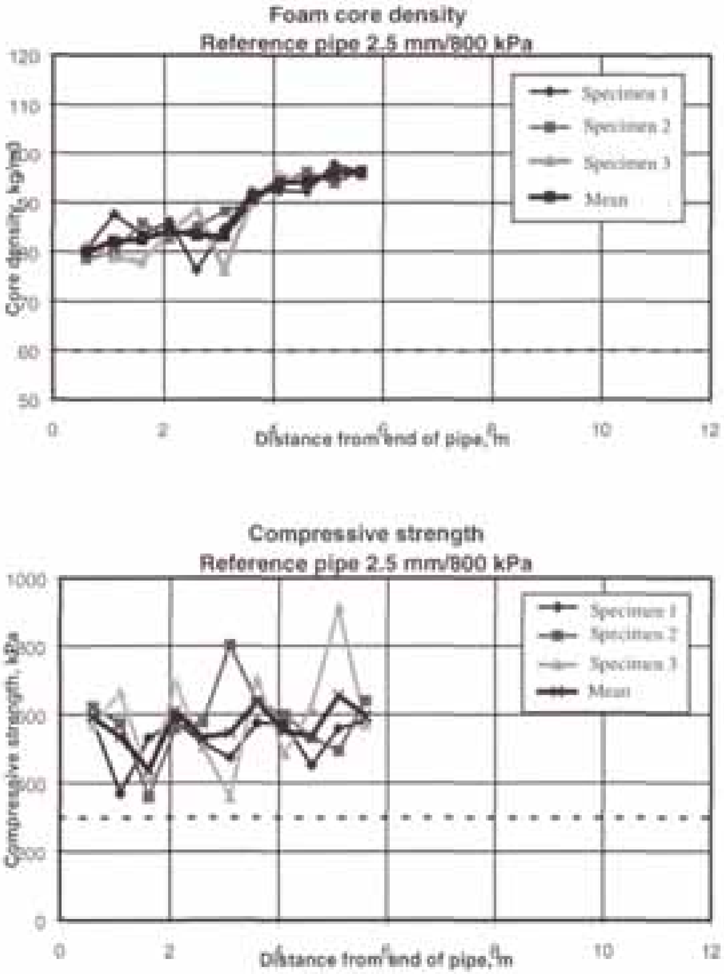


Figure 7.1 *Distribution of density and compressive strength along the pipe*

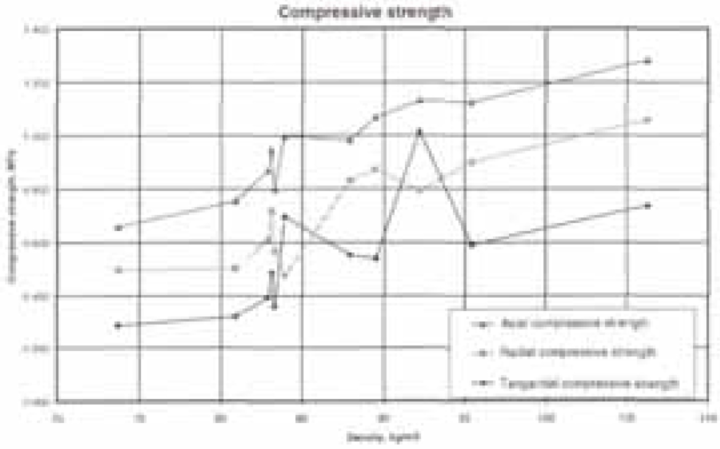


Figure 7.2 *Compressive strength in axial, radial and tangential directions*

It is evident from *Figure 7.2* that the PUR foam is in most cases about twice as strong in the axial as in the tangential direction, and that the radial strength is approximately a mean value. This clearly illustrates a pronounced anisotropy in cell structure and serves as an explanation for the unexpectedly large variation in compressive strengths.

7.2 Axial shear strength

In order to find whether the bond between the PUR foam and, primarily, the casing pipe, had deteriorated during the field tests on the district heating pipes, the shear strength was measured on specimens taken from those parts of the pipes which had been exposed to the greatest traffic loads, i.e. below the lanes which had been used by the dumper traffic.

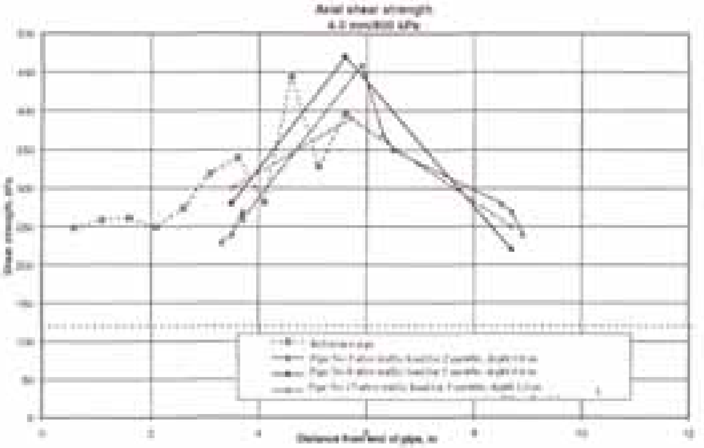


Figure 7.3 Axial shear strength, comparison between reference pipe and pipes in the test

For most pipe types, the shear strength exhibits only insignificant changes, as shown in *Figure 7.3*. In several cases improvements in shear strength were even measured. On the other hand, district heating pipes with the casing pipe made from the material HE3470 consistently show a deterioration in bond after loading. It is worth pointing out in this context that no corona treatment, which can appreciably improve bond strength, was performed on any of the pipes.

7.3 Watertightness of joints after field tests

In leakage tests in accordance with EN 489 [10] on the joints of types Dual Seal and Powerbond which pipes Nos 1 and 6 contained, all joints were found to resist an external water pressure of 35 kPa for 24 hours without any signs of water ingress.

8 Damage

8.1 Permanent indentation in the casing pipe

In a backfill material which contains some larger stones, a badly placed stone may give rise to large local forces on the pipe and cause an indentation in the casing pipe. Even though this does not immediately cause failure, the stress concentration in the indentation zone may initiate crack growth which, if it continues over a long period, may cause breakdown. *Figure 8.1* shows the numbers and sizes of the permanent indentations in the casing of pipe No 16.

Figure 8.1 Number and depth of permanent indentations, pipe No 16 (2.5 mm/300 kPa, 1.0 m)

In order to obtain a better idea of what happens to the pipe near a highly deformed indentation zone, a series of indentation tests were performed in the laboratory. The tests were designed in order to simulate a possible real load combination, but to be nevertheless so simple that the conditions may be easily described as the background to qualitative and quantitative results.

The indenter was a steel ball of 25 mm diameter which, in a MTS 810 universal testing machine, was forced radially against the PEH casing of the pipes studied in the project. One test was made on each type of district heating pipe. The maximum depth of indentation was 10 mm, and the rate of loading 3.5 mm/minute. These conditions were selected in order to simulate conditions during tests on the compressive strength of the PUR foam in accordance with EN 253 [1], in which a rate of deformation of 10% per minute is prescribed.

When the indentation depth of 10 mm had been reached, the deformation was kept constant for 170 minutes (ca 10,000 seconds), after which the relaxation of the applied force was recorded.

Similar tests were also performed on district heating pipes with the casing removed, in order to gain an idea of the differences in rate of relaxation in the PE casing and the PUR foam.

During the initial stage of force application, force increases quite rapidly with depth of indentation. The tangent modulus (the slope of the curve) then decreases and, at a depth of indentation of ca 2 mm, stabilises at a more or less constant value; see *Figure 8.2*.

The results regarding the shapes and levels of the curves are comparable with earlier tests made by Bryder et al [11] in which different ball sizes and rates of loading were however used.

In order to judge how stresses and deformations develop in the pipe over time, the loading situation must be defined. It has been shown for buried pipes [12] that after an initial period a state is reached where deformation is practically constant. This implies that the behaviour of the material at large constant strains and during stress relaxation is critical for the risk of failure in the casing pipe.

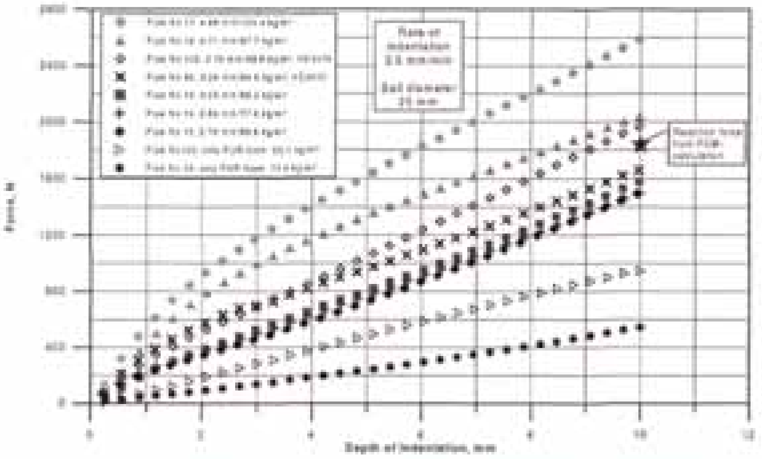


Figure 8.2 Applied force as a function of depth of indentation. The resultant force from the FEM calculation according to Subsection 9.1.2 is also plotted in the figure

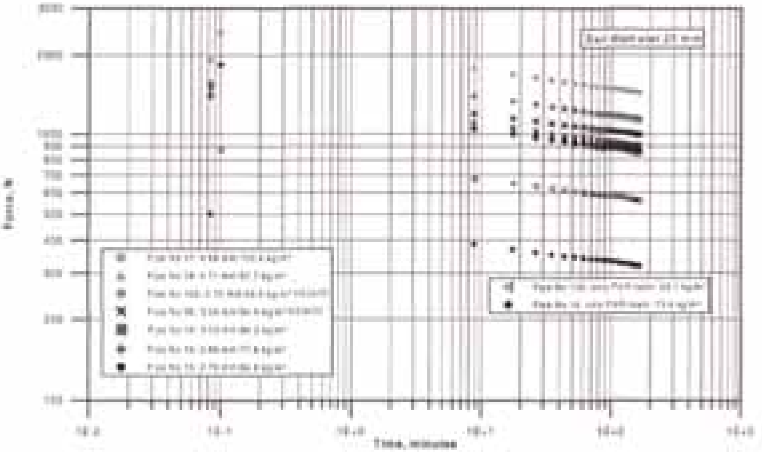


Figure 8.3 Relaxation of force at constant depth of indentation of 10 mm

Measurements of the relaxation of force in the indentation tests were made at 23°C. In all the tested pipes, the applied force relaxed to ca 55-60% of its original value after 170 minutes; see *Figure 8.3*. The same also applies to the tests in which the casing pipe had been removed and the indenter was applied to the PUR foam alone. It would therefore seem reasonable to assume that both materials relax in approximately the same way, and that the recorded relaxation curves can be used in extrapolations of how forces and stresses proceed in the polyethylene material and the PUR foam. Extrapolation of the relaxation curves according to the formula $F(t) = [A \log(t) + B]^{-1}$ shows that after 50 years the force may drop to ca 35%. It must be noted that the rate of relaxation of the plastic material is highly temperature dependent. The tests described above were performed at room temperature. In a pipe in service, it can be expected that the casing pipe will often be warmer because of the high service pipe temperature. This will give rise to a more rapid relaxation process. It is however not certain that the rates of relaxation in both materials change with temperature in the same way.

In order that an assessment may be made of the risk of failure of the casing pipe through slow crack growth in the indentation zone under a stone, the distribution of stresses and strains in the polyethylene material under the indentation must be known. However, the levels of stress and strain which occur in connection with stone indentations are clearly above the approximately linear region which can be used in rough estimates for low loads. This means that stresses and strains must be calculated in view of the nonlinear behaviour of the materials. In an exact calculation, the time dependence of the materials must also be taken into consideration. Such a calculation is however outside the terms of reference of this project. It was nonetheless considered of interest to form a qualitative idea of stresses in the material under a stone indentation. For this reason, a greatly simplified FEM calculation was performed in which the geometry was largely in agreement with the laboratory tests but calculation was essentially simplified by ignoring e.g. the time dependence of the materials.

The FEM model is made up of 6-node triangular elements which are rotationally symmetrical with respect to the left hand edge in *Figure 8.4.*

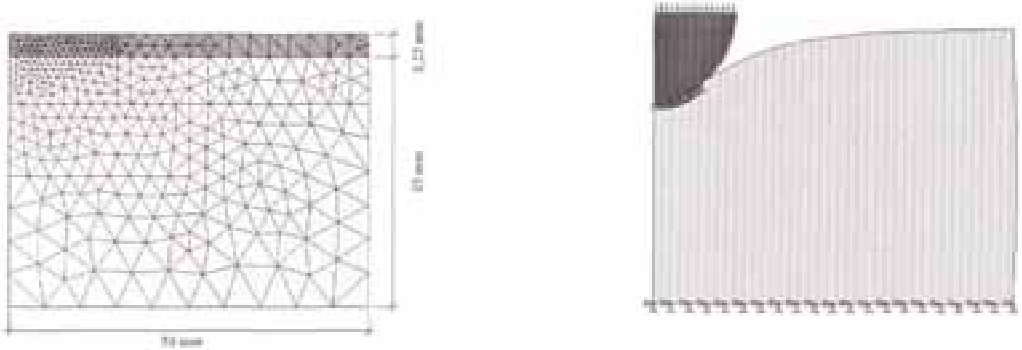


Figure 8.4 FEM model. Mesh and boundary conditions

All nodes have zero prescribed values along the bottom boundary with respect to displacements in both the x and y directions. The way the load is applied is to give the nodes which are in contact with the steel ball a prescribed displacement to the circular arc formed by the shape of the ball. In the experiments it was found that the contact zone between the steel ball and the casing pipe was approximately 15 mm in diameter, and this was also used in the calculations.

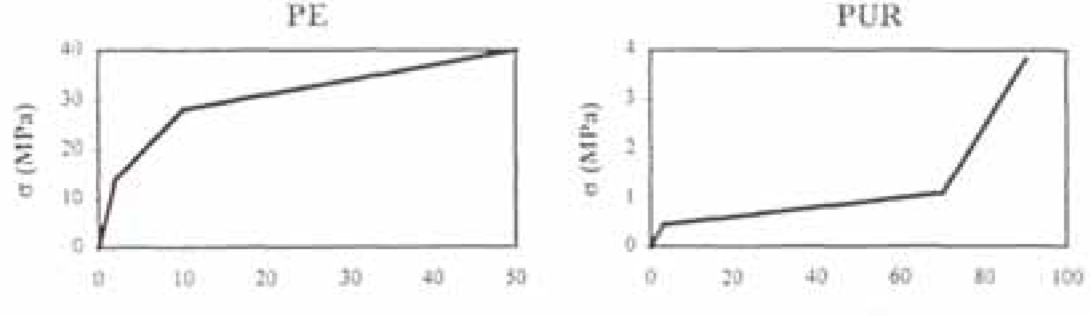


Figure 8.5 Constitutive models for polyethylene and PUR foam

The polyethylene and polyurethane materials were modelled as strain hardening elastoplastic materials with yield criteria according to von Mises [13], [14]; see *Fig. 8.5.*

The simulation was performed as a static calculation at full deformation, i.e. 10 mm indentation below the centre of the ball.

It is evident from *Figure 8.6* below that the casing pipe is subjected to compressive strains at the top and tensile strains at the bottom. This represents the expected large flexural stresses in the polyethylene material. The strains in the horizontal direction (corresponding to tangential or axial directions in a "real" pipe) are ca 14%, which corresponds to a stress of ca 32 MPa according to the material description used.

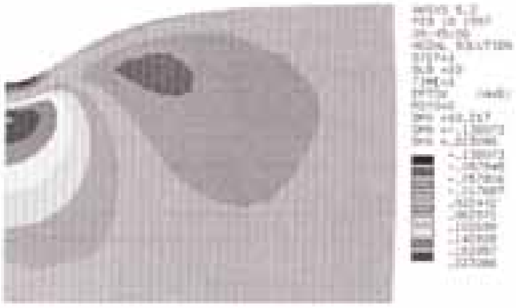


Figure 8.6 Strains in the horizontal direction

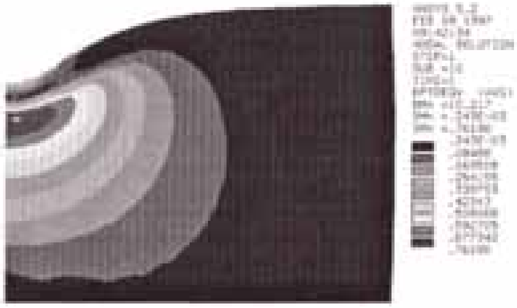


Figure 8.7 Effective plastic strain

The maximum strain in the PUR insulation was calculated as ca 76%, i.e. evidently the insulation is to some extent irreversibly compacted; see *Figure 8.7*.

The resultant of the reaction forces in the contact zone was calculated as ca 1840 N, in good agreement with the experimental results; see *Figure 8.2*.

Since this is a strain controlled loading event, it is likely that the above strains will not deviate greatly from real values. It is however considerably more difficult to express an opinion regarding the stresses, especially in the long term since the materials have temperature dependent relaxation characteristics. An approximate calculation of flexural stresses in the casing pipe after 50 years can be made if it is assumed that the entire tension field relaxes uniformly as in *Figure 8.3*, which would give rise to a remaining stress of ca 0.35 × 32 MPa = 11 MPa. In this context, another factor of uncertainty is that the initial stress level is dependent on the rate at which the indentation is achieved, which may be difficult to judge in a real case.

In order that the service life of a casing pipe subjected to large local indentations may be predicted, it is necessary to know what the behaviour of the polyethylene material is under large constant strains of long duration. There are very few reports of such investigations. An early investigation is reported in [12]. It has however been impossible to find similar measurement results for today's polyethylene materials.

A comprehensive investigation regarding stones in contact with casing pipes has recently been published in Denmark by the *Research committee of the Ministry of Energy for the production and distribution of electric power and heat* [11]. As in this report, a study is made of the effect of short term indentations on cold pipes. The results of a large number of measurement series with different indenters, rates of indentation and district heating pipes of sizes ranging from 90 mm to 630 mm are set out. FEM calculations were also performed on buried pipes in order to find what failure mechanisms are critical in different loading events. The conclusions of the report are that the thickness of the casing pipe on district heating pipes larger than 200 mm in size can, with respect to the risk of stone penetration, be reduced to one half of that prescribed in the current version of EN 253 [1]. No assessment is however presented of the risk of cracking in the polyethylene casing pipe, nor have any data been presented or referred to concerning the way in which the casing pipe material behaves under large strains of long duration.

8.2 Scratches on the polyethylene pipe

When the district heating pipe is displaced axially through the fill material, the compacted material will scratch the casing pipe to a lesser or greater degree.

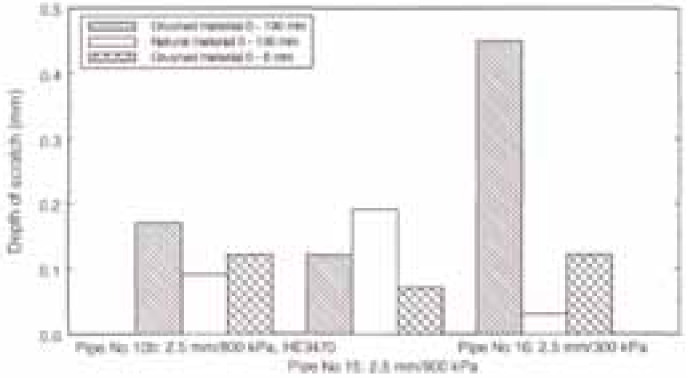
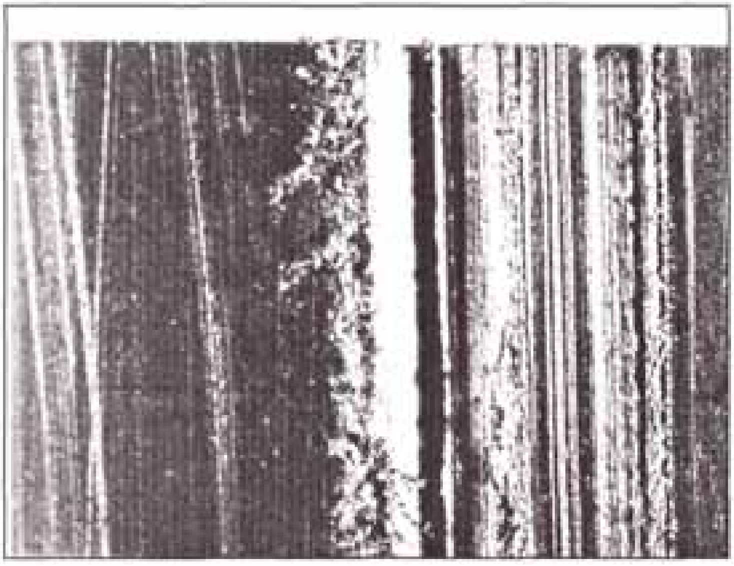


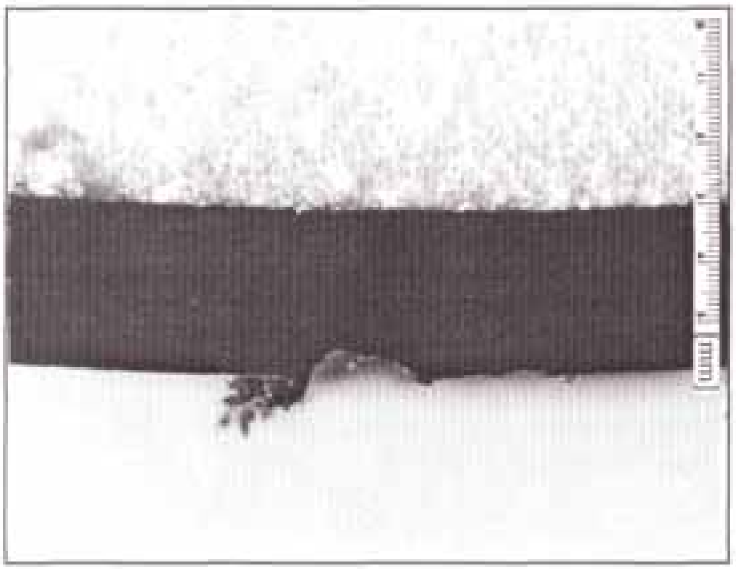
Figure 8.8 Depth of scratch caused by axial displacement

The extent of damage depends on e.g. the magnitude of earth pressure and the length of displacement, the nature of the fill material and the stiffness of the underlying PUR insulation. It may generally be supposed that large and sharp edged gravel fractions will give rise to scratches of greater depth. *Figure 8.8* sets out measured scratch depths.

Figure 8.9 shows the sites of the most prominent scratches on the casing pipe of Pipe No 16 in the different fill materials after 50 cycles of alternating movements. It is seen from the photograph of the cross section that scratches in the "worst" material (0-100 mm crushed material) have a maximum depth of ca 0.5 mm, i.e. ca 20% of the thickness. This is the largest measured scratch depth which could be clearly related to the axial dispacements. The pipes also exhibit a wide range of different types of indentations and scratches caused during transport and handling.



Surface of casing pipe with scratches



Cross section of scratch as above

Figure 8.9 Scratches on Pipe No 16 (2.5 mm/300 kPa), material No 1 (0-100, mm crushed material). 8x magnification.

9 Conclusions

9.1 Construction methods, economy

As described in Chapter 3, in practical construction there are a large number of restrictions which must be taken into consideration when laying a district heating pipeline. This is particularly evident in a city centre environment where there are stringent requirements that disturbance to the surroundings should be kept to the minimum. In such a case, reuse of the excavated material as backfill around the pipe does not result in any major savings in either time or cost. The reason is that transport to and from an intermediate stockpile for the excavated soil and handling are generally needed since there is normally no space for stockpiling along the route of the pipe. It is not until a laying method is employed in which direct transport of fill material from the excavation to the delivery site is possible that an improvement in this respect can be achieved. This would in practice require a simpler jointing technique, and the service and casing pipes would have to be jointed in considerably shorter time than at present. Using such a technique, it would be possible to dig the trench, lay and joint the pipes and deposit the backfill within a working area along the pipeline that is considerably shorter than that required by the technique applied at present.

In parks and natural ground, the possibility of re-using excavated material to a greater extent than today may result in considerable savings and in addition cause less disturbance to the environment. In this case, there is generally space for stockpiling the excavated soil along the pipe trench, and reuse therefore results in savings in both material and transport costs. As an example, the saving in cost for a pipe of dimension DN250 has been calculated at ca 20% of construction costs. Further savings can be made if there is no need to construct temporary transport roads for the haulage of materials.

9.2 The risk of damage and deterioration in the properties of the district heating pipes

The total maximum compression of the PUR insulation as a result of the compaction of the backfill material and the traffic load imposed on the pipe has in field tests been found to be 0.5 mm for a pipe DN65/160. Since the thickness of insulation is 35 mm, compression of this order will hardly cause difficulties.

At the points where there are major indentations by stones, the PUR insulation is subjected to loads exceeding the ultimate strength even when the depths of indentation are moderate. Since this occurs only where stones are actually in contact with the casing pipe, the effect is only local and will not appreciably affect the overall function of the district heating pipe. The resistance of the pipe in this respect can be improved by increasing the density of the PUR insulation and thus its stiffness and strength.

For district heating pipes with casing pipes made of HE2467 BL, no signs of reduction in shear strength could be found. On the other hand, in pipes with casing pipes made of the bimodal material HE3470, a reduction in shear strength could in several cases be demonstrated after the field tests. In addition, in axial tests on these pipes, failure occurred in all cases between the PUR insulation and the casing pipe. It was noted that the shear strength of these pipes was already low when measurements were made on the reference pipes, and it is obvious that further reduction can occur due to mechanical action.

In the case of pipes with casing pipes made of the material HE2467 BL, the test results in most cases indicate an improvement in shear strength in the pipes loaded in the field. It is hardly likely that this occurs because the radial compression exerts a positive effect on the bond strength. It is more likely that it is some kind of postcuring of the PUR material that increases strength some time after manufacture. When the reference pipes were tested, this was probably not manifested to the same degree as after 2 and 5 months.

In the tests no deterioration was found in the watertightness of joints. It should however be noted that none of the joints tested were subjected to axial displacements.

On the tested casing pipes, no damage was found which was attributable to the backfill material and could be regarded as a probable cause of failure. Scratches and local stone indentations of varying sizes occurred during the field tests, but these did not puncture the casing pipe or caused failure of the polyethylene material. It is not until information of a more comprehensive extent is available regarding the resistance of the polyethylene material to high strains of long duration that it can be decided to what extent stress concentrations and points of crack initiation due to stone indentations and scratches can cause failure in a long term perspective. Nor is it evident how the density of the PUR material affects the overall resistance of the casing pipe. Generally speaking, depth of indentation is smaller and flexural stresses in the casing pipe are thus lower when density is higher, but in return contact pressures on the pipe are higher.

10 Recommendations

10.1 Backfill

In order to avoid high point loads and local deformations due to an uneven trench bottom, the following recommendations are made concerning the bedding layer:

A district heating pipe shall at all times be laid on a bedding layer of minimum 100-150 mm thickness. The bedding layer should be sand or gravel of maximum 20 mm particle size. If the bedding layer is also to serve as a drainage layer, not more than 5% of the particles shall be smaller than 2 mm. If the thickness of the bedding layer exceeds 150 mm, it shall be compacted in accordance with MarkAMA 83 (General Material and Workmanship Specifications for Earthworks) [3], Table C/5.

The investigations made in this project on backfill materials containing stones with up to ca 100 mm maximum side length showed that damage in the form of permanent indentations of maximum 4 mm depth occurred on the casing pipes with the softest PUR foam. In pipes with harder foam, maximum indentation was approximately half as large. In axial displacement tests the pipes received scratches with a maximum depth of ca 0.5 mm. Little is as yet known about the long term harmful effects of these indentations and scratches on the polyethylene casing pipe and the PUR foam, and it is therefore suggested that the results of the measurements should be interpreted with some measure of caution until a larger knowledge base is available.

As regards the joints in the casing pipe, no deterioration in watertightness could be demonstrated. No joints were however subjected to displacement tests, and it is therefore not considered that the way these are affected by movements through coarse backfill materials has been clarified.

Apart from providing protection against mechanical damage for the casing pipe and joints, the backfill must also exert sufficient friction against the casing pipe so that the restraint forces assumed during system design of the pipeline are actually realised in the field.

In order to ensure that the pipeline will have satisfactory long term function in both these respects, it is recommended that the backfill up to at least 200 mm above the crown of the pipe should be of material of maximum 20 mm particle size. This material should contain not more than 10% particles smaller than 0.1 mm and the coefficient of uniformity C_u (i.e. the ratio of the sieve size through which 60% by weight of the material passes to the sieve size through which 10% by weight of the material passes) shall be greater than 2. Isolated particles of 50 mm maximum size may occur, but not adjacent to joints in the casing pipe, bends surrounded by backfill or branch connections, unless these have been given special mechanical protection or shown to have adequate strength.

The distance 200 mm above the crown of the pipe is specified in MarkAMA 83 [3] for district heating pipes and has been reproduced unaltered. The reason that this distance is larger than e.g. the thickness of the bedding layer is that there should be sufficient protective fill above the pipe when the rest of the fill is placed which, according to MarkAMA 83, may contain stones up to 300 mm in size.

The backfill is to be compacted in the normal manner according to the recommendations in MarkAMA 83 [3], Table C/5.

The Swedish recommendations [2] assume an effective coefficient of friction of 0.4 in calculating friction forces and friction lengths. In calculating forces at the free end of the pipe, however, it must be borne in mind that the coefficient of friction may have a low value, and it is normally assumed that its value may drop to zero. When the pipe is laid so that its movement is *restrained by friction* exerted by the backfill, the maximum spacing of movement absorbing elements should be equal to twice the friction length. For this method of laying, backfill of low friction such as silt and clay can be used without the design movements and forces in the pipe being exceeded. On the other hand, when the pipe is laid so that its movement is *prevented by friction* exerted by the backfill, the distance between movement absorbing elements shall be greater than twice the friction length, and if backfill consists of fine grained soil which has low friction against the pipe, movements will be appreciably greater than assumed in design. Nor can fine grained material be compacted in practice, and considerable settlement might therefore occur above the pipe, for instance in a street surfacing. However, backfill consisting of fine grained material does not cause mechanical damage to the casing pipe, and can therefore be used on sections where no friction forces are required or where there is no risk of damage due to settlement.

Backfill around bends, when the bend is enclosed in a box or surrounded by insulation slabs and covered with geotextile, can be carried out in accordance with the above specifications. Bends constructed without either a box or insulation slabs can be backfilled with the material specified above, of maximum 20 mm particle size, if the recommendations according to [7] are complied with. This means that the backfill is not compacted over a distance equal to 10 × DN on each side of the bend. In rock or firm soil (hard moraine), the distance between the pipe and the wall of the pipe trench should be not less than twice the outside diameter of the pipe over a distance equal to ten times the outside pipe diameter, measured from the centre of the bend.

As regards the requirements for backfilling around branch connections, neither this investigation nor recent investigations into bends laid without a box or insulation slabs [7] has dealt with this issue. There are thus no new investigation results that warrant an alteration of present practice on this point. The existing pipe laying recommendations [2] refer only to the alternative with a box or insulation slabs (Diagram 5). Obviously, however, branch connections can be laid directly in the ground without a box if they are on a fixed section of the pipe or if movements in this are small. In such cases the requirements for the pipe trench and backfill should be the same as when a bend is laid in firm soil or rock, i.e. the trench is to be widened so that, for a branch connection, the distance between the pipe and the wall of the trench is at least 2 x DN over a distance of 10 x DN, and backfill is to consist of uncompacted material of maximum 20 mm particle size.

Backfill above a level 200 mm above the crown of the pipe is to conform to the method specified in MarkAMA 83 [3], Section C2.5, or to a method specified by the authority in charge of street works or a similar body.

10.2 Pipes

The investigations show that pipes which comply, even when tested after 5 months, with the minimum mechanical requirements in EN 253 [1] (300 kPa compressive strength and 3.0 mm casing pipe thickness for a pipe of nominal 160 mm casing pipe diameter) satisfy the requirements, even when the backfill material with the largest stone sizes (100 mm) is used. No deterioration in axial shear strength has been found for pipes with casing pipes made of HE2467 BL, but this has been observed in casing pipes made of the bimodal material HE3470. It must however be noted that none of the casing pipes tested in the project had been subjected to corona treatment. Such treatment might have resulted in better bond strength, even in the case of the bimodal PE material.

Neither the radial deformation under traffic load nor the local indentations due to pressure by stones are considered critical with respect to thermal insulation capacity and bond between foam and casing pipe.

The maximum measured depth of the scratches which occurred when the pipes were displaced axially was ca 0.5 mm. Not enough is known as yet concerning the risk of brittle failure of the casing pipe due to stress and strain concentrations near scratches and local indentations. The likelihood of crack propagation through the polyethylene casing is primarily determined by the properties of the polyethylene material, but also by the thickness of the casing pipe and obviously by the sharpness and depth of a scratch or stone indentation. Nor is the PUR foam without significance, since it is the stiffness and density of the foam which largely determine the magnitude of deformations near stone identations, and, in turn, this affects the magnitude of the strains in the casing pipe. The more recent bimodal materials exhibit a considerably more ductile behaviour and better resistance to crack propagation than the materials normally used today. There is therefore reason to suppose that the requirements concerning the properties of the backfill material and/or the thickness of the casing pipe can be relaxed, if more stringent requirements are instead specified for the long term properties of the casing pipe material.

The recommendation is thus made concerning the polyethylene casing and the PUR foam that when the pipe is laid with reused backfill material, the minimum requirements in accordance with EN 253 [1] shall be complied with until such time as the long term resistance of the construction to local scratching and indentation has been better clarified.

The investigations demonstrate that all joints are watertight after considerable traffic loading over 5 months. However, the joints were not subjected to axial displacements. It appears however that for pipes whose movement is prevented by friction the construction requirements in EN 489 [10] are adequate when backfill material according to the recommendations in Section 10.1 is used. In the case of joints which may be subjected to axial displacements, however, special investigations must be made of the joint concerned before any recommendations can be given.

It is therefore recommended with regard to joints that the requirements in EN 489 [10] should be applied, so long as the composition of the backfill material is subject to limitations and the joints are protected as set out in Section 10.1. If in future larger stone sizes are permitted even around joints, the requirements concerning approval tests should be extended so as to comprise loading tests in coarser materials than those specified in the present version of EN 489.

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Appendix 2:

TESTING OF COARSE GRAINED HYDRAULIC BACKFILL MATERIAL

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Contents

1 Introduction

This study is a preliminary investigation of the mechanical properties of hydraulically compacted coarse grained backfill material for district heating pipes.

Traditionally, pipe trenches are filled with friction soil which is compacted in a mechanical fashion. The compaction of the soil is necessary to avoid settlements on the ground surface. In the case of district heating pipes, it is also vital to establish a friction restraint between the pipe and the backfill material in order to diminish the pipe movements due to thermal expansion of the steel pipe.

By using hydraulically compacted backfill, the required stiffness, strength and friction properties can be obtained without the effort of mechanical compaction. Instead, the soil is stabilized by adding a small amount of cement and mixing it with water.

Because of the risk of damaging the pipes, the composition of the backfill material has traditionally been restricted to relatively fine grained fractions, typically < 8 mm. However, recent investigations have shown that coarser material can be used under certain conditions, and that this may lead to substantial cost savings [4].

The purpose of this project has thus been to examine the hydraulic compaction used in conjunction with coarse grained backfill material, and in particular to evaluate the friction coefficient and compressive strength of the mixture.

2 The stabilized sand mixture

The stabilized sand mixture can be characterized as a concrete with a very low cement content. The formula for 1 m^3 of the mixture has for this project been as follows:

•	Sand/stone aggregate	1550 kg
•	Standard cement	20 kg
•	Water	approximately 100 kg

In addition, a porosity admixture labelled Peramin L manufactured by Perstorp AB has been used.

The mixture was prepared at the laboratory with the aid of a concrete mixer in batches of approximately 200 litres. Water was added until the consistency of the mixture was deemed appropriate for filling the moulds.

Three different aggregate compositions (see table 3.1) with largest grain size ranging from 8 mm to 90 mm have been used.

Material No.	*1*	*2*	*3*
Max. grain size	8 mm	32 mm	90 mm
Sand, 0 – 4 mm	50 %	50 %	50 %
Crushed stone, 4 – 8 mm	50 %	25 %	16 %
Crushed stone, 16 – 32 mm	—	25 %	17 %
Crushed stone, 63 – 90 mm	—	—	17 %

Table 3.1 Aggregate compositions, percentage by weight

3 Compressive strength of the sand/cement mixture

The method for evaluating the compressive strength of the sand/cement mixture was adopted in part from the American standard method ASTM C 39 - 86 for compressive strength of cylindrical concrete specimens [2]. The sand/cement mixture was poured in PVC pipes of inside diameter 290 mm. The heights of the specimens were approximately the same as the diameter. The samples were allowed to harden for 15 days before the compressive tests commenced.

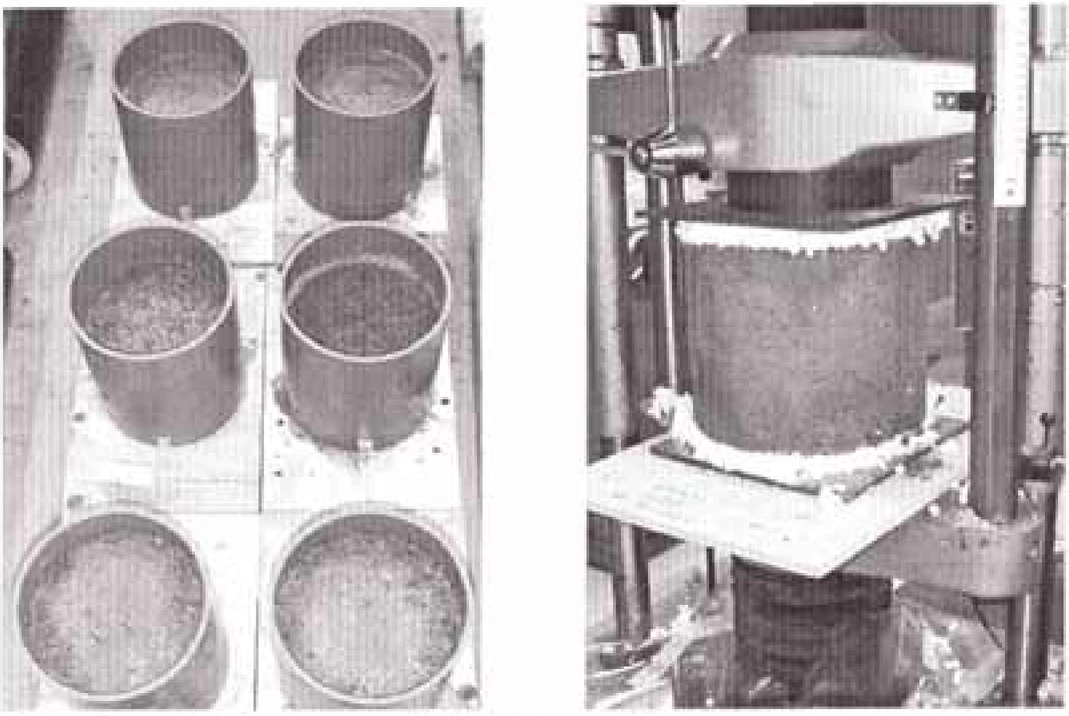

Figure 3.1 a) Samples poured in PVC pipe moulds

b) Sample during compressive strength test

In order to get an even pressure distribution on the top and bottom surfaces of the samples during the compressive strength test, slabs of polystyrene cellular plastics were placed in between the samples and the pressure plates, cf. figure 3.1b.

A total of six tests were made, two for each material type. The loading rate was approximately 1.3 kPa/second. The results are presented in the table below.

	Max. grain size 8 mm	Max. grain size 32 mm	Max. grain size 90 mm
Sample	σ_{max}	σ_{max}	σ_{max}
1	229 kPa	185 kPa	214 kPa
2	220 kPa	233 kPa	176 kPa
Mean	*225 kPa*	*209 kPa*	*195 kPa*
Grand average			*210 kPa*

Table 3.2 Compressive strength

The results indicate that the strength of the sand/cement mixture decreases somewhat as the coarseness of the used aggregate increases.

The compressive strength is, quite naturally, several orders of magnitude smaller than what can be expected for ordinary concrete. In fact, 210 kPa is in the vicinity of the strength for cellular plastics normally used under road pavement structures. This indicates that the sand/cement mixture is strong enough to be applicable as backfill wherever one would use mechanically compacted sand.

No measurement of compressive strength was performed on samples younger than 15 days. However, the mixture poured in the wooden boxes (see section 4) has been found to withstand at least 50 – 60 kPa after 24 hours of hardening time, determined by walking on the surface.

Although a sufficient strength is required, a too high strength will be a great disadvantage. In the event of pipeline failure, it must be possible to open the trench and excavate the pipes. The experiences gained during the course of this project show that excavation of hydraulically compacted material constitutes no problem. It can be done by hand with a spade, although with slight effort.

4 Pipe/backfill friction properties

The friction between the pipe and the stabilized backfill material has been evaluated by applying a longitudinal movement to a pipe arranged in a wooden box filled with the sand/cement mixture, cf. figure 4.1. The inner dimensions of the box were $2000 \times 550 \times 500$ mm^3 (L×W×H). The wooden box was placed inside a larger steel box normally used for testing of district heating pipe joints in accordance with EN 489 [1]. The displacement of the pipe was accomplished using a hydraulic jack and the friction force was measured with a force transducer connected between the jack and the pipe. The jack was controlled to give the pipe a constant longitudinal displacement rate.

A position transducer was used for measuring the steel pipe displacement relative to the wooden box. Furthermore, the shear deformation of the PUR foam was followed using a second transducer measuring the difference in longitudinal displacement between the steel pipe and the casing pipe, cf. figure 4.2.

In order to simulate field-like conditions, a static pressure was applied to the surface of the sand/cement mixture. The magnitude of the surface pressure was adopted from EN 489 [1], in which it is stated that a total overburden pressure corresponding to a fill height of 1 m with a backfill density of 18 kN/m^3 shall be applied.

To facilitate a uniform pressure distribution, the comparatively hard surface of the sand/cement mixture was covered with a thin layer of sand on which 60 mm thick concrete tiles were placed. With the aid of a hydraulic jack and a system of steel girders, the surface pressure was applied as shown in figure 4.3. Using a pressure gauge connected to the hydraulic system, the magnitude of the surface pressure was calculated.

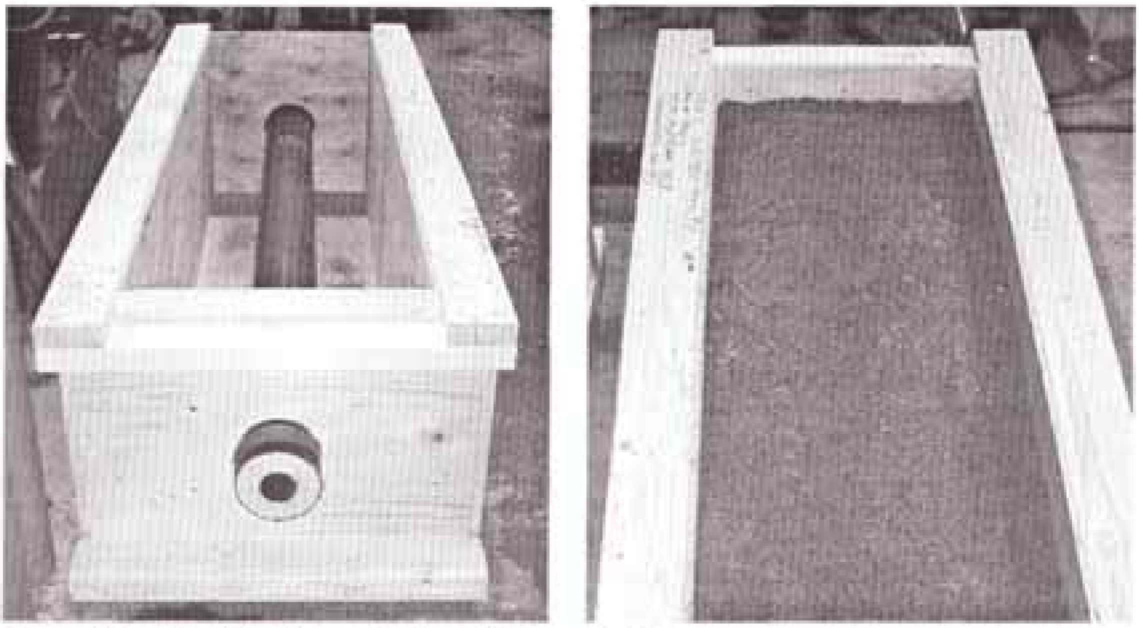

Figure 4.1 a) Empty wooden box with mounted pipe
b) Wooden box with sand/cement mixture after approximately 24 hours of hardening time

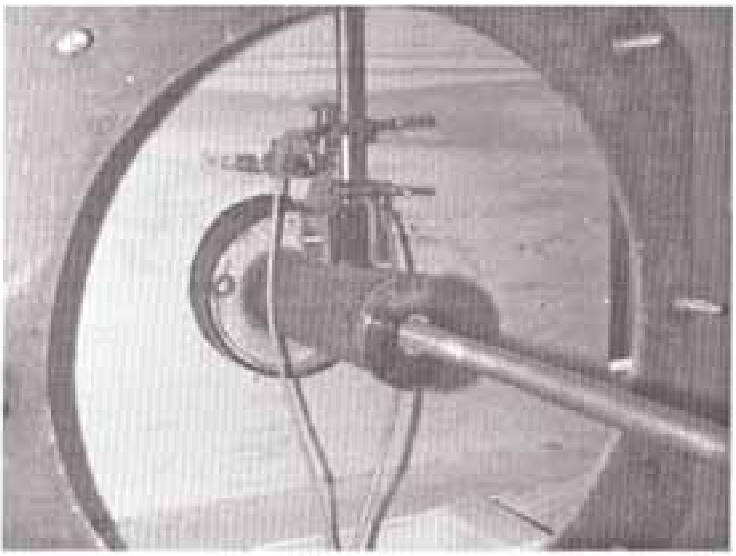

Figure 4.2 Transducers in place

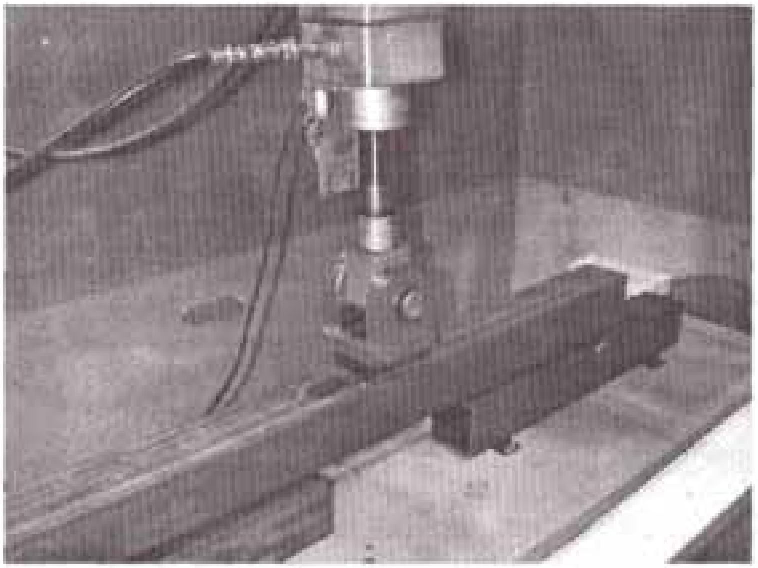

Figure 4.3 Hydraulic jack and girder system for applying vertical surface pressure

The pipes were displaced approximately 50 mm at a rate of 1 mm per minute. During each run, the force, the steel pipe displacement and the shear deformation of the PUR foam was measured and logged with a Datascan 7221 Measurement Processor.

Preinsulated pipes DN 65 with a polyethylene casing pipe of diameter 160 mm were used. The pipes have previously been used for the field trials described in [4]. They have not, however, been subjected to any longitudinal displacement prior to this test. A total of three runs were made, one for each type of backfill material.

Figures 4.5 and 4.6 show the friction force plotted against the steel pipe displacement with different scalings on the horizontal axes. The friction force is expressed as force per meter pipe length, i.e., total displacement force divided by the length of the pipe.

The discontinuous appearance of the 90 mm curve is due to bad control in the hydraulic system which the computer program could not handle. The movement of the pipe was momentarily halted. After starting again, the force did not reach quite the same level.

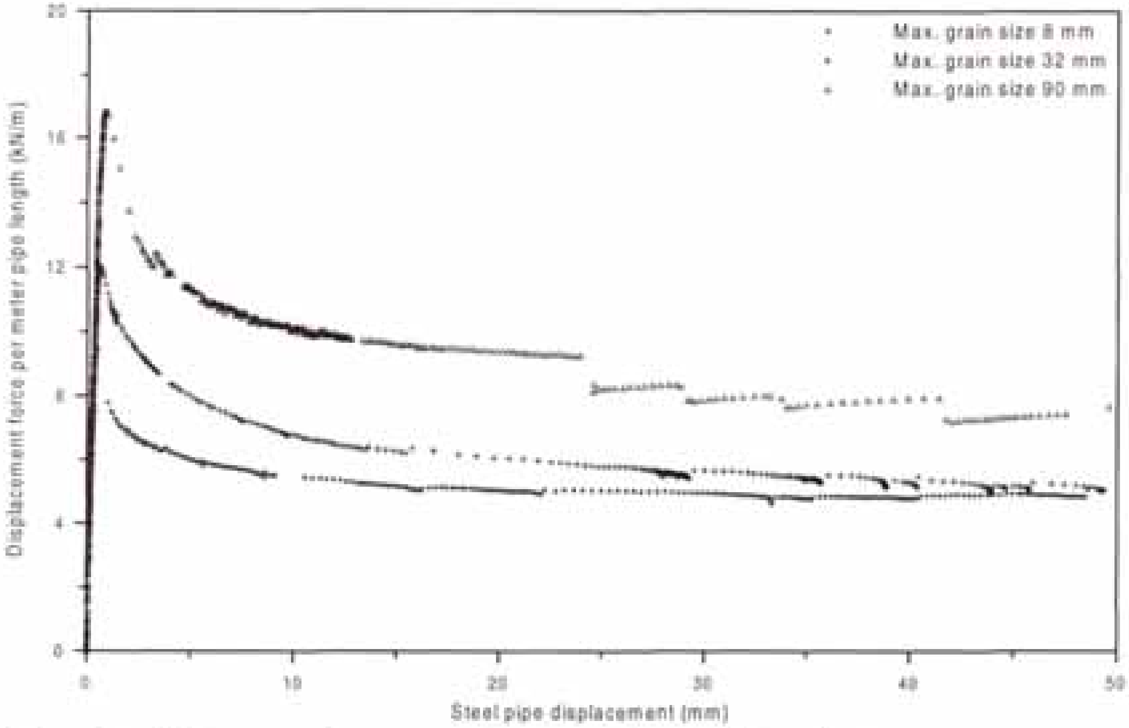

Figure 4.5 Displacement force per meter pipe length vs. steel pipe displacement

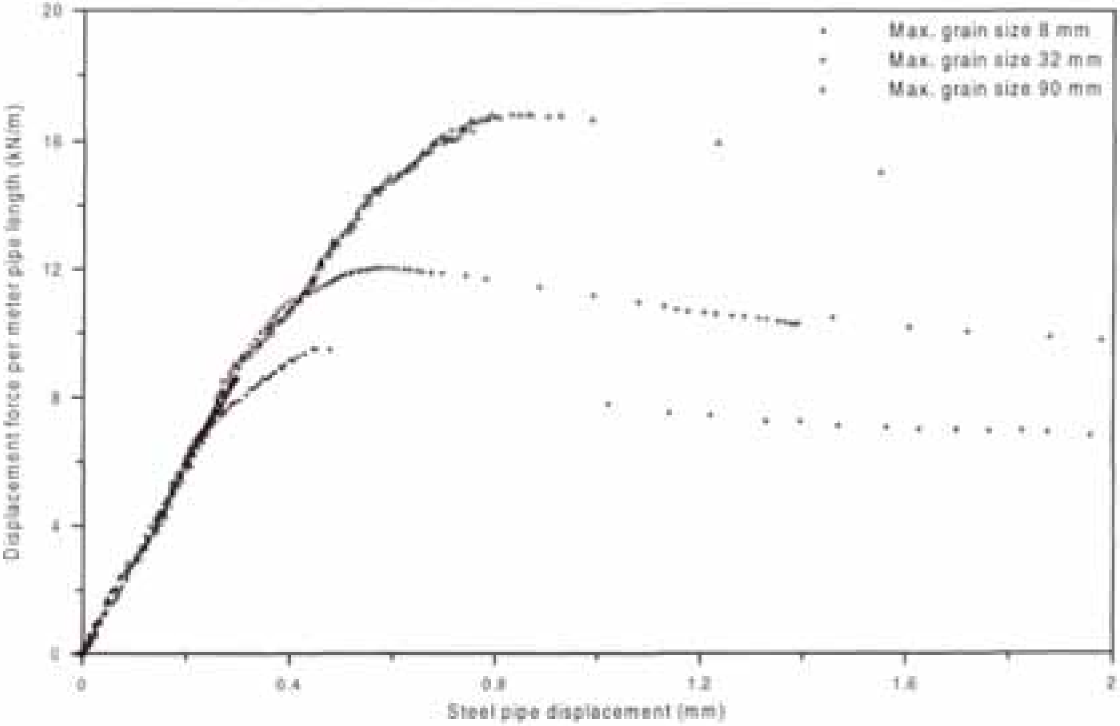

Figure 4.6 Displacement force per meter pipe length vs. steel pipe displacement

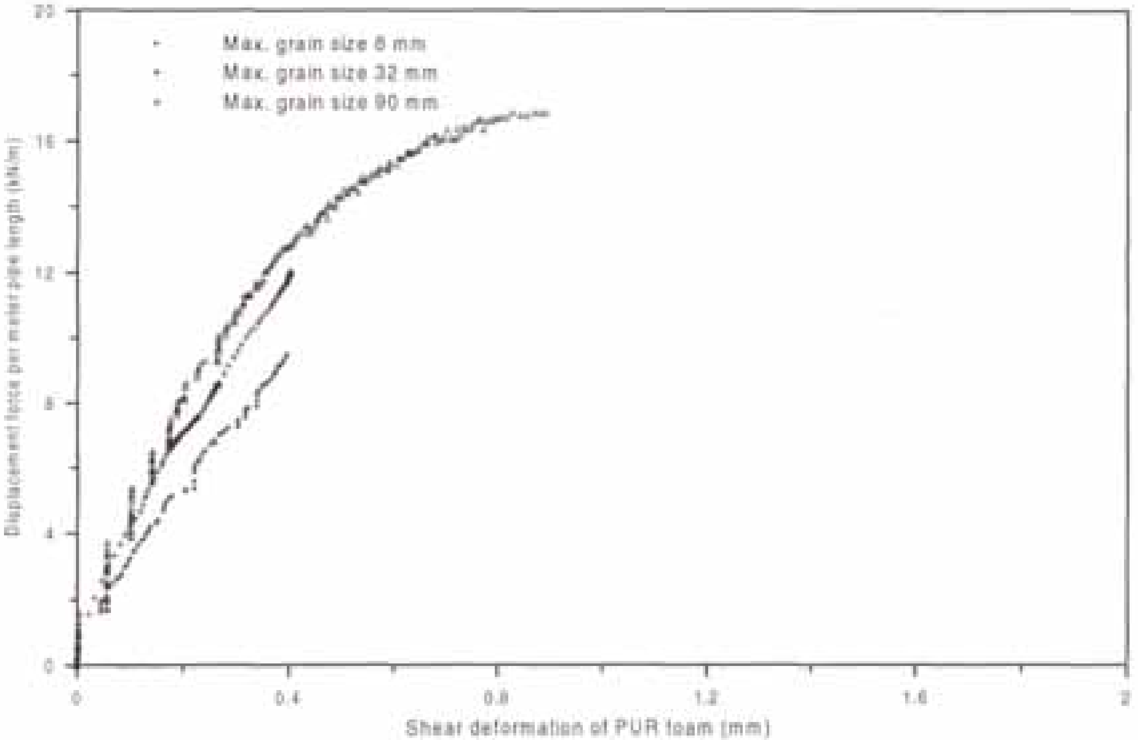

Figure 4.7 *Displacement force per meter pipe length vs. shear deformation of the PUR foam (i.e. the difference between the longitudinal displacements of the steel pipe and the casing pipe)*

All curves display a clear peak force, at which the casing pipe is pulled loose from the backfill material. After that, the force gradually decreases to a residual value. This behaviour is quite different from what is seen for pipes buried in ordinary backfill material. In such cases, a peak value is not seen. Instead the force increases gradually up to the constant value.

The steel pipe displacement prior to the peak force is mainly caused by shear deformation of the PUR foam. The shear deformation, expressed as the relative displacement between the steel pipe and the casing pipe, is plotted vs. the friction force in figure 4.7. By comparing figures 4.6 and 4.7, it can be seen that the shear deformation is almost as large as the steel pipe displacement up to the peak force. This means that the casing pipe hardly moves through the backfill at all before the peak force has been reached, which indicates a very stiff friction bond before the pipe has been pulled loose for the first time.

The large non-linear shear deformations exhibited by the pipe buried in the 90 mm material (cf. figure 4.7) is probably caused by shear failure between the PUR foam and the casing pipe.

The friction between the pipe and the backfill material is normally discussed using a friction coefficient, μ, expressing the ratio of the longitudinal force to the restraining force resulting from the earth pressure acting on the pipe wall:

$$\mu = \frac{f_x}{\int_0^{2\pi} \sigma_r(\varphi) r_C \, d\varphi} \tag{3.1}$$

where f_x is the longitudinal displacement force per meter pipe length (N/m), σ_r is the earth pressure acting in the normal direction on the pipe wall (Pa), r_C is the radius of the casing pipe (m) and φ is an angular coordinate.

The above expression is often simplified (see e.g. [3]) to

$$\mu = \frac{f_x}{\gamma H \pi D_C} \tag{3.2}$$

where γ is the density of the backfill material (N/m^3), H is the fill height (m) and D_C is the casing pipe diameter.

By using this simplification, one assumes that the earth pressure can be described as a hydrostatic pressure acting at depth H from the surface. This implies that the force needed to displace the pipe longitudinally is directly proportional to the overburden pressure. In the case of cement stabilized sand however, the friction coefficient seems to be much less dependent on the overburden pressure. This is possibly due to a much stiffer behaviour of the sand/cement mixture compared to ordinary sand. The backfill material surrounding the pipe are thus less prone to deform, and the normal pressure against the casing pipe wall will not increase as much with the surface pressure as for ordinary backfill materials.

Listed in table 4.1 are the friction forces and friction coefficients calculated according to expression (3.2). For the 90 mm material, the residual value has been extrapolated from the smooth part of the curve. The curves for the 8 mm and 32 mm materials appear to converge at large displacements to a friction coefficient of approximately 0.5 – 0.55.

	Friction force, f_x (kN/m)		*Friction coefficient, μ*	
Max. grain size	*Peak value*	*Residual value*	*Peak value*	*Residual value*
8 mm	9.5	4.9	1.05	0.54
32 mm	12.0	5.2	1.33	0.58
90 mm	16.8	~8.6	1.86	~0.95

Table 4.1 Friction forces expressed as force per meter pipe length and friction coefficients

Similar measurements of friction coefficients for coarse grained backfill material subjected to mechanical compaction is described in [4]. The friction coefficient for a 0 - 100 mm crushed material was calculated to 0.71 after 50 cycles of 40 mm displacement back and forth. It was also found that the friction force after 50 cycles was about 50 % smaller than the initial value during the first displacement. This would indicate that the initial friction coefficient for a mechanically compacted 100 mm material is about 1.4, to compare with approximately 0.95 for a hydraulically compacted 90 mm material.

It is not clear whether the decrease in friction force for cycled displacements will be as obvious for material compacted hydraulically as for those compacted mechanically. Due to the cement stabilizer, the material might not have the same tendency to "loosen up" as ordinary sand and gravel.

5 Voids in the pipe/backfill interface – Pipe damage

The interface between the pipe and the backfill material must not contain too many voids (areas where the backfill material is not in contact with the casing pipe) in order for a sufficient friction force to develop. One might expect that coarser gravel fractions will result in larger pores leaving contact gaps at the interface. Furthermore, a large stone, surrounded by an air gap, pressing against the pipe constitutes an unfavourable load case for the HDPE material in the casing pipe. It was shown in [4] that coarse backfill materials may cause severe localized deformations of the casing pipe due to contact pressure from adjacent stones. Thermally induced movements may also cause scratching of the casing pipe at the contact zones. On the other hand, if the interface in the vicinity of the stone is completely filled with fine material, the pressure at the contact zone will be reduced.

After the friction force tests were finished, the wooden boxes were broken and the pipes were excavated in a fashion which allowed for examination of the lower half of the pipe/backfill interface.

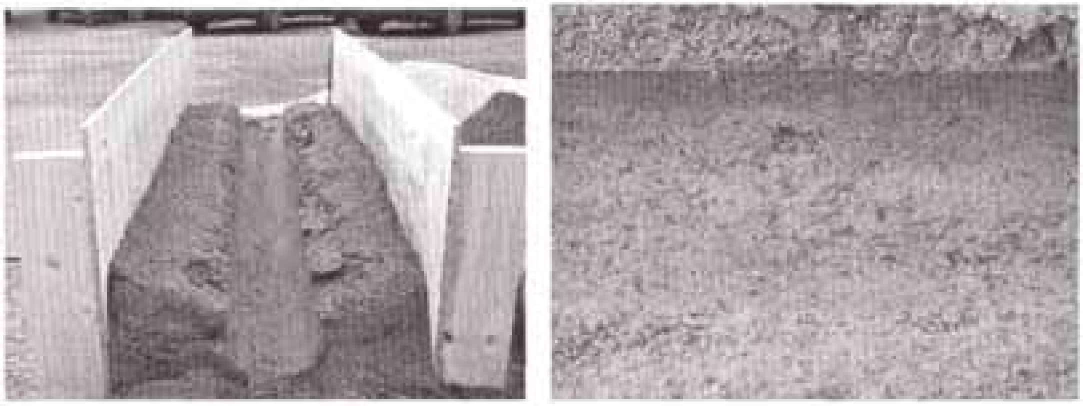

Figure 5.1 Pipe/backfill interface, max. grain size 8 mm

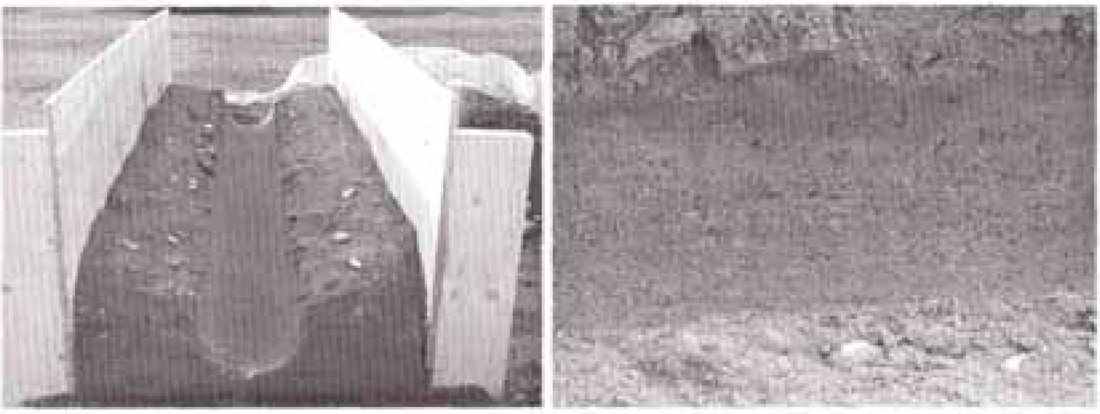

Figure 5.2 Pipe/backfill interface, max. grain size 32 mm

Figure 5.3 Pipe/backfill interface, max. grain size 90 mm

The interfaces of the two coarse materials are almost entirely smooth with no significant voids at all. For the fine grained material however, there is a streak of small voids running along the bottom of the pipe. This indicates that the occurrence of interface voids is more a question of workmanship during the filling of the trench rather than an inherent property of the stabilized sand mixture.

After excavation, the pipes were examined with respect to indentations, but as one might expect from looking at the interfaces, there were no visible indentations to be found.

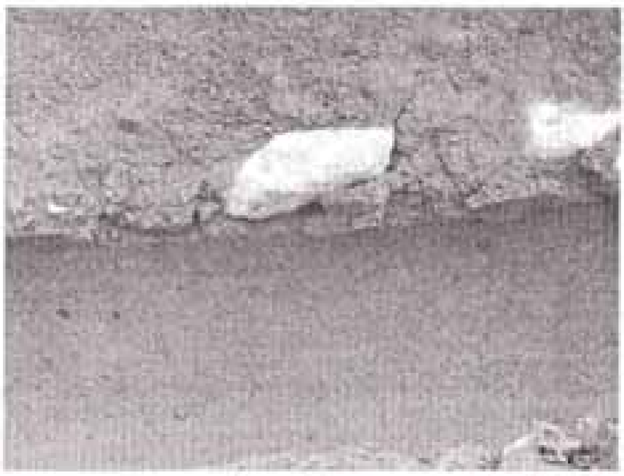

Figure 5.4 Large stone previously in contact with the casing pipe, max. grain size 90 mm

Figure 5.4 depicts a large stone which after the test was observed to be in contact with the casing pipe. The contact region was examined for any signs of damage caused by this stone, but none were found. As these pipes have been used for experimental purposes once before, the casing pipe surfaces exhibit a wide variety of minor scratches and marks due to burying, excavation, transport, etc. It is therefore not possible to conclude that *no* scratching of the pipes has occurred while buried in the hydraulically compacted material. But it is safe to say that no major damage has occurred during the displacement test.

6 Conclusions

The compressive strength of the cement stabilized material was measured to approximately 200 kPa. It is thus strong enough to be used under road pavements, and it hardens fast enough to allow walking on the surface after 24 hours. This means that reinstallment work can be undertaken without significant delay. The sand/cement mixture is still quite easy to crush, so it is possible to excavate the pipes if necessary.

The friction coefficient is slightly lower than for mechanically compacted backfill material with comparative grain sizes. It is however well above the standard value of 0.4 normally used for pipeline design.

Previous investigations involving coarse grained materials point out the risk of large stones damaging the casing pipe. Such effects have not been seen throughout this study. Probably the comparatively stiff sand/cement mixture provides better protection for the casing pipe than ordinary backfill material.

The results from this study thus indicate that hydraulically compacted coarse grained backfill material constitutes an interesting alternative for the laying of district heating pipes.

As seen from similar experiments with mechanically compacted backfill materials, the friction coefficient decrease significantly with repeated displacement cycles back and forth. Future investigations have to make clear how the friction coefficient develops during cycled displacements in hydraulically compacted materials. It is also crucial to examine the risk of damage by localized point loads from stones pressing against the casing pipe, and to what extent this risk might be diminished by using hydraulic compaction instead of mechanical.

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