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IEA District Heating and Cooling

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

Cold Installation of Rigid District Heating Pipes

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Cold Installation of Rigid District Heating Pipes

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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 startet 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 cold installation 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
- N.P.Garrod/Matt Grace, 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 and Mr. Sirola for their special contributions of material from Sweden and Finland.

Content

1 Summary

Today, thermal pre-stressing of the pipes is generally avoided when they are laid by the cold installation method.

With today's practice of cold pipe installation the design stress parameters are not any longer limited by the material's 0,2% yield strain. Of all possible options cold pipe installation is the simplest kind of laying technology which opens new and effective possibilities of construction-site organization. With appropriate preparation the activities can be performed in a single-day-construction manner.

The static stresses caused by cold pipe installation exceed the stresses resulting from the 0.2% yield strain. The design is governed by a fatigue analysis based on the appropriate number of load cycles for district heating. Hence, the material's mechanical stress resistance is used to an extensively high degree.

With cold pipe installation resulting stresses can reach the stresses of the actual yield strain. As a consequence, the pipe endings which are generally located in the expansion zone undergo considerable displacements. Solutions have been worked out to control the high stresses and strains. These are described in the later sections of this report. In general, operating the system at moderate temperatures cuts back some of the disadvantages and restrictions of the cold pipe installation method.

The method of cold pipe installation is definitely applicable today. The decisive questions concerning material stresses are solved both theoretically and experimentally. An increasing number of companies does cold pipe installation using several years of experience particularly those made in Denmark, Sweden and Germany. Further investigations will be likely to bring along simplifications in the design of service connections.

The predominant advantage of cold pipe installation is the reduction of construction time and costs. Extensive investigations of the time span of construction have shown that construction time decreases to 67% and costs to 81% when compared to pipe laying by ways of thermal pre-stressing.

2 Introduction

2.1 General

The supply with district heating, which is regarded as less-polluting and resource-conserving, can be expanded as much further as pipelines can be installed more cost-efficient. Therefore, many initiatives aim at the reduction of pipeline construction costs. One of the possible solutions is the cold installation of pipes. In contrast to the commonly applied laying technology it takes advantages of an increased utilization of the pipe-system's mechanical strength. However, cold installation techniques require a more detailed stress analysis as a basis for design.

Nowadays, bonded preinsulated pipes are used almost exclusively when buried district heating pipeline systems are installed. These systems are international state-of-the-art. As they use rigid steel pipes as medium pipes only these systems are being dealt with in this report. A series of European Standards already exists on technical specifications of the raw material [6 to 9], another standard is currently being prepared for the design, layout and laying of this pipe system [1]. Besides this, flexible preinsulated pipes are coming up on the market and will become more important in furture.

2.2 Layout of Bonded Preinsulated Pipes (BPP) and their Previous Development

There are different ways of layout of BPP-systems. In the course of time knowledge on the mechanical behavior of this system and calculation methods have been improved. The mechanical layout which was done quite roughly in the beginning has improved gradually, while decisive steps were caused by the gained knowledge on reliable specifications of the raw material (aging, shear- and compression resistance of the PUR-foam, elasticity of the expansion pads) and, among others, by more precise measurements of the bedding forces acting on the pipe system.

The term >>cold installation<< is used for a specific way of pipeline design in the scope of this report and, therefore, shall be defined at this point. The definition has to take into consideration the international language, e.g. as provided in [1], [2]. The definition becomes more complicated, because the meaning of the term >> cold installation << is somewhat misleading when interpreted on the grounds of colloquial speech. For the ease of understanding the text's most important terms are listed and explained at the end of the document.

Cold installation is defined most vividly, if one imagines which path of development the layout of BPP has followed since its first application:

Using the first BPP-systems one managed the elevated material stresses due to thermal expansion by limiting the length of the straight pipe runs to so-called >>maximum permissible straight laying length<<. (The supply hot water temperature commonly known beforehand was the basis for the layout). This length was derived from the material's 0,2% yield strain. At those times, pipes were buried at ambient temperature, >>cold<<, so to speak.

This laying-technique required many cost-intensive measures for the compensation of pipe expansion, e.g. axial compensators, expansion pads, etc.

The full utilization of the mechanical strength by means of pre-stressing allows for a maximum temperature-increase of 160 K without having to deal with plastic deformation of the steel (no safety factor towards the yield strain). Consequently, based on the stress related temperature yield for steel a peak temperature of 160 + 10 = 170 °C could be permitted. However, the temperature yield of the PUR foam (about 130 °C) is limiting the system's overall range of application. With thermal pre-stressing the pre-heating temperature is chosen so that the pipe's maximum stresses of expansion and compression become almost alike.

The thermal pre-stressing of BPP brings along the disadvantages of additional costs plus extra effort to keep the pipe trenches open for a rather long time which, in turn, requires trench-bracing, provisional trench bridges etc.

For these reasons one aimed to get along without pre-stressing, of course, still keeping the freedom to install infinitely long runs of straight pipeline.

Thereby, the 0.2 % yield stress for the usual pipe-steel that had been generally accepted as absolute stress limit, was exceeded inevitably. Naturally, this stress occurs according to large temperature increases, for instance, at a heat-up step of $\Delta T=80$ K in addition to the ambient temperature (i.e. 10°C), equal to a preheating temperature of 90 °C. Going beyond stress yields is permissible and in accordance with the rules of mechanical layout because the pipes are operated at fairly steady temperatures; they are seldomly shut down and are exposed to moderate temperature variations, only.

Of course, the static mechanical layout becomes more involved since the pipe must be designed according to the material's creep rupture strength and, in addition, the creep rupture properties have to be obeyed.

For the above kind of layout the term >>cold installation<< was introduced. Naturally, the described technique of limited permissible straight pipe length that obeys the 0.2 % yield strain and requires frequent expansion bends can be entitled as cold installation, too. However, it is a technology that has been applied for 35 years yet and shall not be described again in this report.

The following text focuses on the new technology of >>cold installation<<, speaking of those types of layout where the 0,2% yield strain is not limiting the design, anymore.

Finally, it is pointed out that the term >>cold installation<< is defined independently relating to the compensation of the pipe's thermal expansion, i.e. expansion pads among others.

2.3 Cold Installation

The cold installation does not require pre-heating of the pipes. Only at high temperatures the pipe is compressed irrevocably because in normal operation stresses remain inside an amplitude-margin that is lower than both of the elastic yield stresses, compression and expansion. For all the following temperature variations the pipe is deformed within its elastic limits. The one-time plastic deformation of the pipe's material is permissible due to the preservation of the material's mechanical strength.

The cold installation is a way of layout district heating pipelines operated at water temperatures beyond 90°C and laid without pre-heating. The design of cold installed pipes accounts for the comparatively low number of full load cycles of district heating systems and, therefore, takes advantage of the maximum permissible yields stresses gained by a fatigue analysis (definition).

The increased utilization of the steel's strength, as a consequence, leads to elevated stress. Unlike pre-stressed laying [15] this causes much higher displacements in the expansion zones.

The current considerations must be seen in connection with the long term experiences from which is known that the nominal design strength of steel tubes does often exceed its standard yield values by far. The calculation parameters for the strength of the steel, e.g. $R_{e,T}$, are the manufacturer-guaranteed lower limits. For instance, the standard yield stress of St37 totals 204 N/mm^2; practice-proven values are in the range of 270 N/mm^2 [16]. Consequently, the actual yield strain is not reached even if the system is operated at temperatures in excess of 90°C. However, with cold installation and rising temperatures stresses eventually increase towards the yield strain. If the maximum operation temperature is kept below the actual stress value that will deform the material the resulting peak stress corresponds to the thermal stress.

So far, two cases are to be distinguished with respect to cold installation:

1. The yield strain is being exceeded by the first heat-up to maximum temperature. Thereby, the pipe is plastically compressed and remains tensionally stressed when cooled down to ambient temperature. This process is referred to as auto-pre-stressing.

2. The operation temperature of the network is moderate and the actual yield strain is not reached. This means that at maximum operation temperature a stress is obtained which is higher than the permissible stress of e.g. 204 N/mm² for conventional design.

3 Special Features of Cold Installation

Due to the higher permitted material stress the cold installation leads to higher demands for the system. From this, peculiarities are derived, which have to be considered for the layout, construction and operation of district heating pipes.

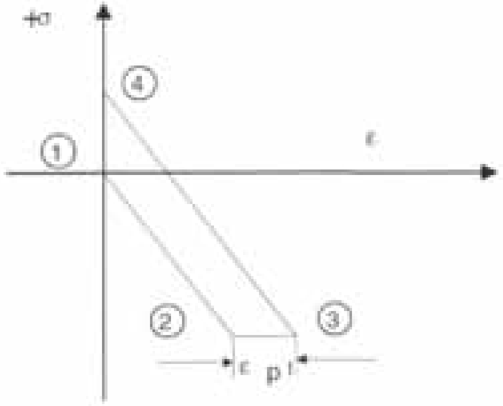
Table 3-1: Special features of cold installation

Project Phase	Peculiarities	Measure	Paragraph
Design /Layout	High stress and displacement of the pipe ends	Layout after well known methods. Special measures for the compensation of expansion: - pre-stressing the expansion pad - anchor bridge - one-time compensator - pressure bend - System 4	 4 4.1 4.2 4.3 4.4 4.5
	High compressive stress in the pipe	Examination of the stability - against revolting - against buckling - against cracks, e.g. at free ends inside shafts	5.2
	Calculation of wall thickness of - bends - tee - branches - reducers	When necessary under consideration of the bedding force with reinforced wall thickness	
	Mitres and gussets	Generally not permissible	
Components	Tees, reducers	Reinforcement	
	Components for higher pipe stress	reinforced housing	
Construction	Expansion pad	Pre-stressing through: 1. subsequent burying 2. mechanical preliminary pre-heating and welding	4.1.1 4.1.2
	One-time compensator		4.4
Operation	Parallel Excavation	Danger of buckling, adjust operation temperature accordingly	6.1
	Repair	Caution when cutting the pipe! Fixture for handling only nearby the expansion bends	6.2
	Hot tap	Reinforcement of the medium pipes	6.3

These peculiarities are listed in Table 3-1, where in column 4 reference is made towards the paragraph of this report in which the particular problem is addressed.

3.1 Stresses and Displacement

Fig. 3-2: Elastic and plastic stresses at cold installation (idealized)



The thermal pre-heating of BPP is applied to reduce the stress of the pipe material. The cold installation doesn't apply pre-heating and therefore leads to higher stress and displacement during operation.

According to the definition of cold installation the permissible stress $\sigma_{zul} = S * R_{0.2,T}$ is exceeded and perhaps to the extent of plastic deformation. This fact is illustrated in Figure 3-2.

A rigidly clamped pipe is warmed up starting at condition ①. It reaches the elastic yield stress at point ② and then deforms irrevocably up-until state ③ is reached (plastic deformation). During recooling to the initial temperature the pipe stress decreases to $\sigma=0$ and then changes into tensile stress at state ④.

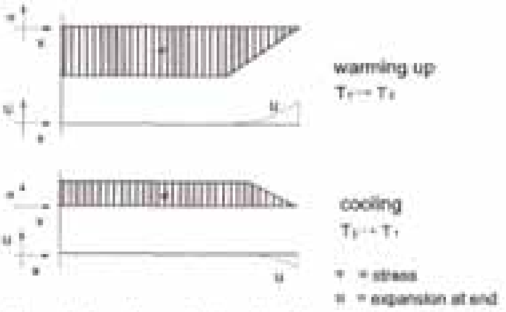
Remark:

Figure 3-2 also shows the technical limit of application for the cold installation with reference to the temperature. Because the maximum increase of σ is given by the value $+R_e$ at state ④ cold installation is limited to twice the temperature variation between state ① and ②. Adding the ambient temperature of 10 °C that yields

$$T_{max} = 2 * 80 + 10 = 170 \text{ °C}$$

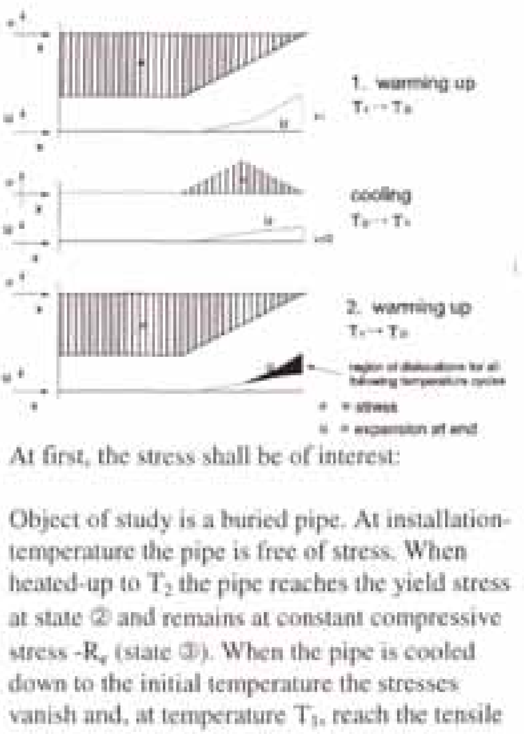
The actual operating temperatures of district heating grids are lower.

Fig. 3-3: Cold installation exceeding the actual yield strain



For piping the relationship between stress and displacement in the restrained and the expansion zones is commonly drawn versus the pipe length. Fig. 3-3 shows the stresses and displacements of various temperatures for a pipe section which deforms plastically like described by Fig. 3-2 (for reasons of symmetry only one half of the pipe is shown).

Fig. 3-4: Cold installation without reaching the elastic yield stress (idealized)



At first, the stress shall be of interest:

Object of study is a buried pipe. At installation-temperature the pipe is free of stress. When heated-up to T_2 the pipe reaches the yield stress at state ② and remains at constant compressive stress $-R_e$ (state ③). When the pipe is cooled down to the initial temperature the stresses vanish and, at temperature T_1, reach the tensile stress $+ \sigma_4$. Now, the pipe is put to tensile pre-stress. Below the stress-diagram the corresponding end-displacements u for the states ③ and ④ are provided.

If one takes a closer look at specific district heating design one will realize, that often the pipe material's yield strength is not reached. Auto-pre-stressing does not take place because calculations have been based on property values for R_e that were lower than the actual ones (see Paragraph 2.1).

For pipelines that do not reach their yield strain, the relation between stress and strain is governed by Hooke's law which is a linear relationship as shown in Fig. 3-2. When the pipe is heated-up to its nominal design temperature T_D for the first time the compressive stress σ_D is obtained. The related displacement of the pipe end is u_2.

If one cools down the pipe to its initial temperature T_a again, the restrained section goes back to zero-tensile stress $\sigma=0$. In the expansion zone friction forces are still acting thus restricting the relaxation of the pipe's end to $u_2/2$. All temperature variations following the initial full heat-up cause movements of the pipe ends in the range between u_2 and $u_2/2$, that is a range of $\pm u_2/4$.

Considering the direction of stresses only compressive stresses appear while heating up from ① to ② (according to Fig. 3-2), of which the highest are in the fully restrained zone. In contrast tensile stresses only appear in the expansion zone and they are of smaller magnitude.

Summing up from the viewpoint of statics the following can be stated on cold installation:

1. The stresses in the pipe and the related components are very high and may approach the elastic yield stress when high operation temperatures are imposed.

2. The displacements of the pipe's end are roughly three to four times higher than with thermal pre-stressing.

Besides, all regulations for the mechanical design of cold installed pipes are provided by [1, 2, 3] among others.

3.2 Consequences for System Layout

The high niveau of stresses as a consequence of cold pipe installation causes enlarged expansion zones and increased displacements at the pipe end. Branches in the expansion zone have to be designed to meet the increased strains.

3.2.1 Measures to Control the High Displacements

According to the depth of laying and the diameter the displacement of the pipe's end can exceed 100 mm considerably. In paragraph 5 an example is given of a DN 250 pipe with 45 cm distance between pipe and surface. In this example a displacement of (2 x 80 =) 160 mm would result (Fig. 5-5). Movements of this great extent can not be handled by conventional expansion pads anymore. As commonly known expansion pads are not installed beyond a critical thickness in order not to overheat the muffs at the outer casting. Depending on the thickness of the pads the trench may also need to be wider than usual.

Expansion pads are installed in thickness less than 12 cm [1], for temperature reasons mostly even with a maximum of 8 cm. Since the pads' ability to be compressed is used only by 60% max. displacements of 50 to 80 mm are the actual displacement yield (compare remark in paragraph 4.1). If larger displacements have to be managed special measures must be taken. The following solutions are known:

Pre-stressing of the expansion pad: Since only the initial heat-up of the pipe to its design temperature causes the high displacements, see Fig. 3-4. Expansion pads should be installed in a way, that their stress-less position be in the middle of the operational movements. Then they will offer the best elasticity. Accordingly, they can be installed with minimum thickness or, described differently, a pre-stressed expansion pad can take the largest net movements.

The desired neutral position of the compensation, i.e. the middle position of the piping in the pad at a certain operation temperature, is obtained by pre-stressing of the pads. For the pre-stressing two methods are approved:

1. Thermal pre-stressing

At start-up the expansion pads inside the not-backfilled man-holes are automatically pre-stressed. After backfilling the expansion pads are in neutral position and, therefore, can compensate movements due to warming or cooling in the best way possible.

2. Mechanical pre-stressing

- Anchor bridge: The supply pipe, which encounters a stronger expansion than the return pipe, is rigidly fixed to the return. The anchor bridges reduces the displacement of the supply pipe by enlarging the displacement of the return pipe.

- E-muff: The E-compensator is deformed once during start-up and then welded.

- Pressure-resistant bend: This bend does not take the thermal expansion itself, but allows displacement of the soil by means of its high compressive strength. The pressure-proof bend is not always necessary. If the reaction forces of the soil remain moderate as is the case in unpaved areas, even the standard bend can move the soil without buckling.

- System 4 (Lögstör)

All the above methods of compensation are described in greater detail in the course of chapter 4.2.

3.2.2 Consideration of High Stress

The largest stresses appear in the restrained zone of the buried pipe and decline towards the bend which is at the end of the expansion zone. All components of the pipe system must withstand the acting forces.

- if necessary, tees have to be built with reinforced walls

- bends should be designed obeying the bedding forces as long as they are not housed inside cavities

- if needed, reducers are to be built with reinforced walls

- when drilling (hot tapping) pipes while they are in service the ratio of diameters must be taken into consideration. It may become necessary to reinforce the pipe

- in the zone of completely restrained pipe an exchange of the pipe sections is easy since pipe material can be built in at ambient temperature like in new construction projects (no preheating). In the expansion zone the pipe must be locked with a fixture prior to cutting similar to thermally pre-stressed pipes.

The high stresses have further consequences, which can be derived from the static strength analysis:

- with cold installation angular deviations of the pipe route are limited to a minimum. This is because extreme strains are expected on the pipe's inside which can cause early breakdowns.

The amount of the irrevocable strain depends on the actual temperature difference. Therefore, the permission of small angular deviations has to be decided based on the prevailing temperature variations.

- for a temperature variation ΔT of 120°C no angular deviations are permitted (inaccuracies of assembly of up to 0,25° are tolerated)

- according to the temperature variation ΔT the following yield values for angular deviation have been approved[1]:

ΔT = 110 °C permissible angle of mitre 0,5°
ΔT = 100 °C permissible angle of mitre 1°
ΔT = 90 °C permissible angle of mitre 2°

Larger angles can be permitted, if better steel qualities are used as pipe material.

A mechanically favorable alternative to mitres (angle of angular deviation) is the pipeline-laying method. The pipe run is welded from straight pipe segments and the required changes of direction are done by elastic bending of the pipe.

- Another alternative is the use of curved pipes, which for large diameters can be custom made at the manufacturer or for smaller diameters bend at the construction site.

- Safety from buckling: With enlarged diameters the danger of deformation (buckling) is increased. Because of the high stresses cold installation is approved only up to DN 400. Here, the yield can be extended if higher quality steel is used.

The stability of the pipe is guaranteed, if the remaining strain extends over the full pipe-length and does not concentrate locally. By a series of tests one was able to prove, that the friction between pipe and soil causes an even plastic deformation of the pipe except in a few number of cases, e.g. at locations of angular deviation, where more detailed calculations become necessary [15].

4 Constructions for the Compensation of Expansion

Most times in cold installation the well-known plastic foam pads are applied to absorb the large expansions. Besides, special designs exist for expansion-compensation, which have been tested just recently. Solely the so-called E-muff is in service for quite long already, although it has yet been applied in network construction only in certain areas.

4.1 Pre-stressing of the Expansion Pads

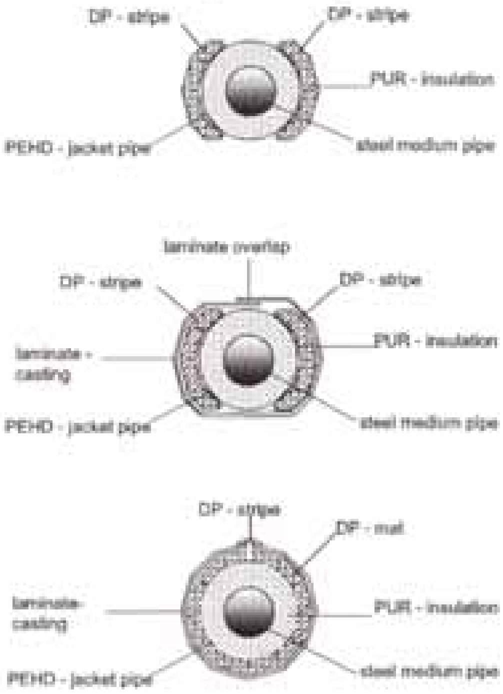


Fig. 4-1:Examples of expansion pads from [3]
Top: Stripe-pad
Middle: Partial padding
Bottom: Full padding

The common types of expansion pads are shown in the Fig.4-1. It is important that the expansion pads don't loose their elasticity due to the penetration of sand. This danger rises when installing in the range of groundwater. Also, expansion pads may not insulate the district heating pipe that much, that the permissible jacket temperature of 60 °C is exceeded. Otherwise the muff joints would be in danger. A partial padding of the pipe shall allow for an improved heat-removal. Expansion pads are used up to a maximum thickness of 12 cm, in most cases smaller thicknesses are permitted, only.

Remark: The numbers given are meant to give a proximate impression, they are no reference values. Since the heat-up of the jacket pipe that is wrapped by foam-pads depends on the operation temperature thicker pads can be used at lower temperatures. Pads shouldn't be overcompressed mainly for reasons of longevity.
Even elevated water-content of the soil reduces the jacket temperature and thus allows for thicker pads. Specific data need to be considered for the actual layout.

4.1.1 Later Backfilling of the Expansion Zones (Thermal Pre-stressing)

In order not to have to layout the expansion pads according to the large displacement caused by the first pipe-heat-up, the pipe can be backfilled completely leaving the expansion zones open.
Afterwards, the pipe is heated to a temperature which results in a pipe-shift to the no-stress position according to the later imposed temperature cycles. At this temperature the expansion pad excavations are backfilled. This method of thermal pre-heating is achieved most conveniently when combined with first start-up of the pipe. In principal, this procedure equals the one used at thermal pre-stressing. It is also possible to do the warming with alternative techniques such as electrical, low-pressure steam, boiler.

With this type of construction the thickness of the expansion pad can be reduced considerably or, putting it differently, this way the large expansions of cold installed pipe can still be handled by expansion pads. In the prestressed expansion pad displacements are of no greater extent than with thermally pre-stressed laying.

Advantage: No additional components

Disadvantage: A hole in the expansion zone is not backfilled until late; this might restrict civil engineering work.

4.1.2 Mechanical Pre-stressing

Aiming to utilize the expansion pads to their full extent the no-stress position of the later temperature cycles is put in the center-position of the expansion pads. This is done by the following way of installation:

The largely completed cold pipeline is buried completely, while just one man-hole in the distance of about one pipe section is kept open.

Here, the pipe remains unconnected and the opposing pipe ends keep a gap which resembles the pre-stressing length of the expansion pads. Now, a device is fixed to the pipe ends by means of which the pipe ends are pulled together, as illustrated by Fig. 4-2.

The bend that will take the expansion is pulled into the pad and then the pipes are welded together. Now, the trench can be filled-up completely. After heat-up the pipe will just move around the center position of the expansion pad.

Advantage: The entire pipe can be finished.

Disadvantage: Higher complexity of construction

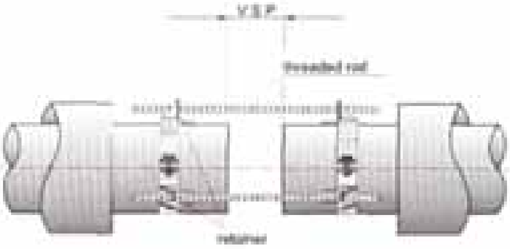


Fig. 4-2: Sample of a device for mechanical pre-stressing

4.2 Anchor Bridge

Since the anchor bridge is a component which was developed and introduced only a few years ago, it will be presented here more comprehensively. Anchor bridges are no custom-made parts anymore but can be directly ordered from the pipe manufacturer.

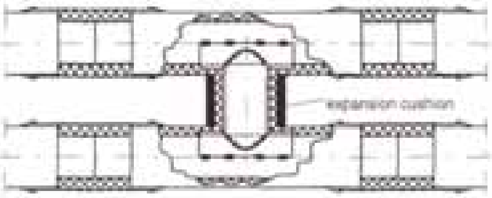


Fig. 4-3: Anchor bridge

The anchor bridge is inserted to manage the high displacements of BPP - piping. It uses the smaller displacement of the return pipe in order to reduce the large displacement of the supply pipe. Both pipes are rigidly fixed to one-another thus limiting the expansion of the supply pipe and increasing expansion of the return pipe.

The anchor bridge may be used for all nominal sizes of BPP while it has to be designed accordingly. The bridge has to be used where movements are large - at the end of the expansion zone. It is important that the advantages of the anchor bridge do not only apply for the main pipe. At the same time efforts for compensation at the branches can be reduced, too. Fig. 4-3 shows the drawing of an anchor bridge. The medium pipes are reinforced in the area of the bridge. The connecting bar between supply- and return-pipes is padded by an expansion cushion.

The rigid connection between supply- and return-pipes in combination with free bedding would lead to bending of the twin-pipe (bi-metal-effect). However, bending is prevented through the pressure of the covering soil.

Installation and function of the anchor bridge are presented by Fig. 4-4. Presented are the pipe routes with the customer connections for both cases, with and without anchor bridge. The strain of the supply pipe which is drawn to scale is reduced significantly by the bridge. With vertical laying the reduction is even more significant than with horizontal laying. The situation shown in Fig. 4-4 accounts for vertical laying type.

From a thermodynamic point of view the connection between supply- and return-pipe represents an undesirable heat bridge. More exact calculations show, that the exchanged amount of heat is negligible. About 4000 anchor bridges would heat-up the return flow by around 1 K.

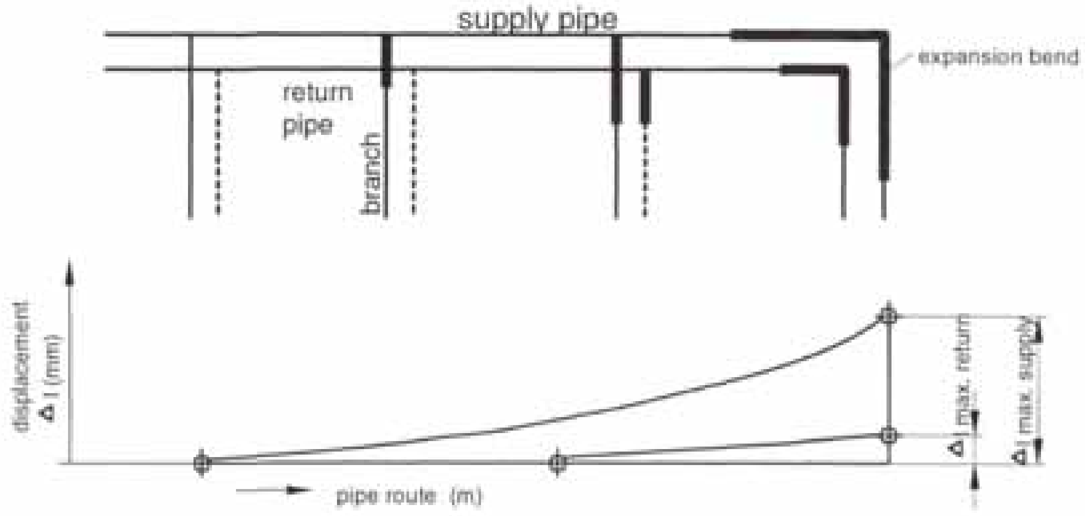
The specific consequences of the installation of an anchor bridge can be visualized by the example of Münchwälder Straße", which is presented in Fig.4-5. There, the exact shifts of supply and return pipe are displayed the way they would be with and without anchor bridge. Also, the stress in the steel medium pipe are pointed out.

The overall message is, that the anchor bridge is a component which can reduce displacements quite significantly when used with cold installation.

Advantage: The pipe can be completed and backfilled; not even mechanical pre-stressing is necessary anymore.
Disadvantage: Custom part; no stock item

Fig. 4-4: Functions of the anchor bridge

Laying without Anchor Bridge



Laying with Anchor Bridge

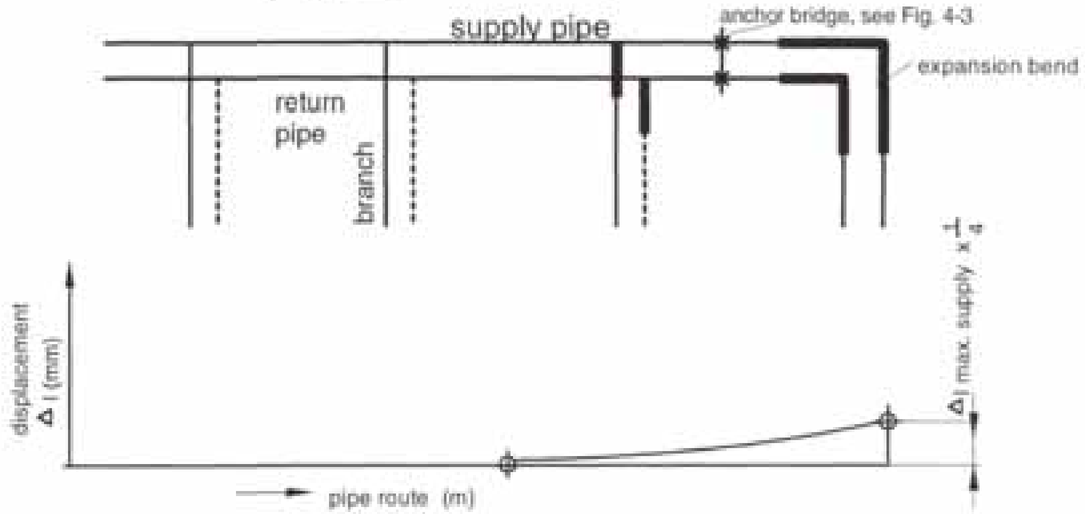
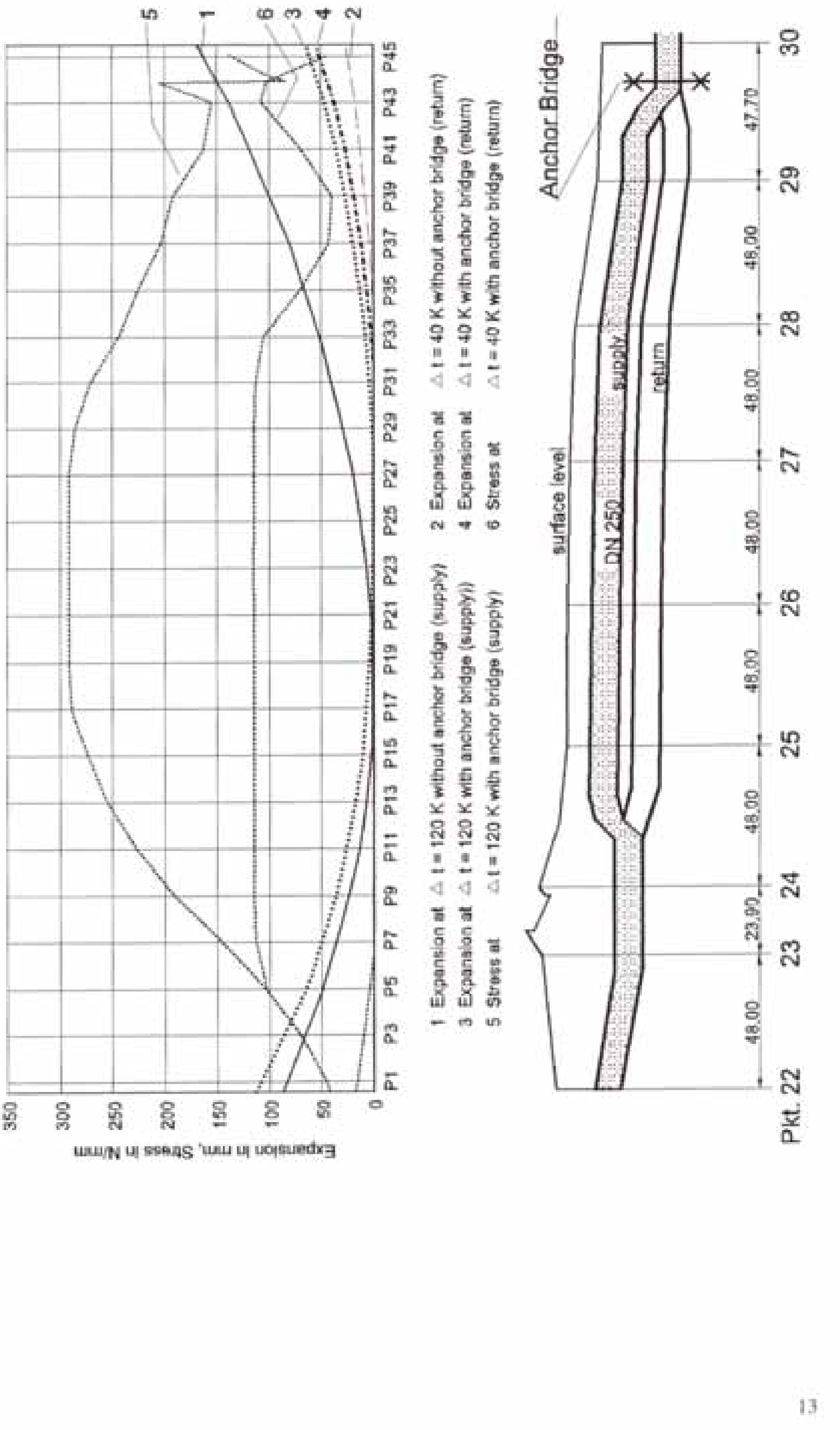


Fig. 4-5: Comparison of displacements and stresses at different ΔT with and without anchor bridge, example D-Mannheim, "Mönchwalder Straße"



4.3 One-Time Compensator

The one-time compensator is a component which is welded to the pipe at the construction site. It permits an axial compression and is fixed after a certain displacement by welding together its outside guiding-tubes. Fig. 4-6 sketches a frequently used one-time compensator, the so-called E-muff of the ABB company.
The function of the one-time compensator is best described by looking at the stress-condition at certain temperatures, referring to the cases 1 to 4, Fig. 4-7. The manufacturer describes the function of the E-muff as follows:

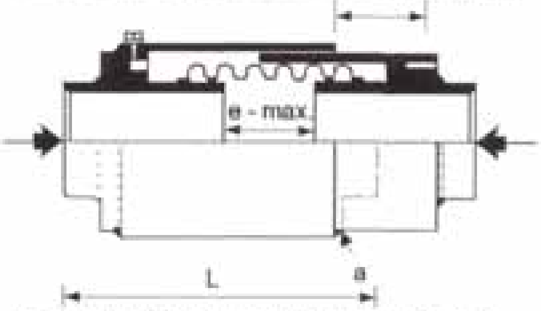


Fig. 4-6: One-time-compensator, type ABB E-muff

The E-muff is adjusted in a way, that it will take the displacement of a certain pipe length R at average operation temperature. At start-up time the pipe experiences a change of length ①. The E-muff is compressed so far that the pipe faces touch inside the bellow ②. At this position the outer guiding tubes of the E-muff are welded together so that the entire pipe is fixed and there are no further movements of the steel pipe. Temperature variations in the steel pipe are turned into permissible compressive- and/or tensile stresses ③. After some thermal cycles the peak stresses have equalized ④. After start-up the system acts like a thermally pre-stressed system. The E-muff then has the length L.

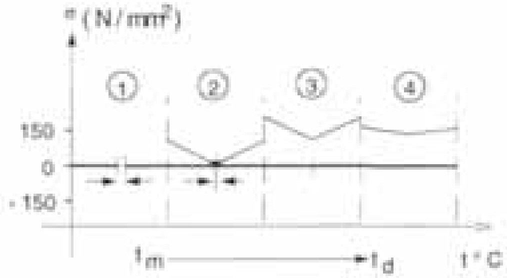


Fig. 4-7: Stress along the medium pipe near a one-time compensator

To be able to enlarge the distance between adjacent E-muffs (costs!) the pipe is covered with foil before burying. The foil causes more equal and lower friction along the pipe. The expansion bend does not need foil-covering.

Principally, the one-time compensator has the same effect as pre-stressing. It shifts the zero state of stress and movement for later temperature cycles towards the average operation-temperature.

The one-time compensator is in service for a long time and being used successfully by some companies.

Advantage: The one-time compensator reduces the displacements of the pipe; it allows for immediate trench-backfilling except man-holes for the one-time compensators.

Disadvantage: The pipe has to be heated-up almost to the design temperature in order to exceed the friction drag. This is the only way to obtain the wanted strain.

4.4 Pressure-Resistant Bend

The pressure resistant bend is a novel strengthened component for the BPP - system. From the outside it looks like a traditional bend but contains a more load-carrying PUR-foam. The foam is reinforced with Foamglass-granulates and has about 10-times higher compressive strength than non-inforced foam. The pressure-resistant bend withstands higher soil-pressure as occurs in the soil even below paved surfaces (in the unpaved terrain a standard bend is sufficient due to lower soil-reaction-pressure).

The pressure-resistant bend can take large forces not requiring expansion pads. It is pressed into the surrounding soil.

Technical Specifications

Density	> 200 kg/m^3
Pressure Resistance	about 2.0 N/mm
Deformation	n.a.
Thermal Conducitivity	0.058 W/mK
Max. Operating Temperature	140° C
One-Time Peak-Temperature	150° C

Fig. 4-8: Pressure-resistant-bend (Tarco, DK)

The pressure-proof PUR-foam transfers the bedding forces to the steel tube, so that inside the steel very high stress occurs and the wall thickness of the bend has to increase. The state of stress has been measured and verified in test construction sites (D-Cologne).

The pressure-resistant bend allows for arbitrary pipe routing. By its use, pipe bend angles of 15 up to 75° become possible which could not be handled by conventional bends due to high displacements.

The pressure-resistant bend has yet been tested by some German district heating utilities, while only a small number has been used for DH-grids so far. Also, a transportation pipe-line in Copenhagen was equipped with a few pressure-resistant bends of size DN 300.

The pressure-resistant bend is a new element for compensation with special advantages for cold installation. It saves displacement pads which are regarded as weak spots of the BPP-system ever since. In addition, leak control systems can be integrated.

From Swedish expectations the benefits of the pressure-resistant bend will be less than originally anticipated. Since it has been proven that even standard PUR-foams feature twice the pressure-resistance than stated by EN 253 already most of the benefits of the pressure-resistant bend can be achieved by the use of ordinary elements.

Advantage: The pressure-resistant bend substitutes expansion pads and transduces the thermal expansion directly into the soil.

Disadvantage: Custom-made part, not available from stock. No on-site-assembly bends available.

4.5 System 4 (Lögstör)

The installation system 4 of the Lögstör company, DK, divides the traditional expansion zone in several sections of compensation. In each section a stress-reducer is inserted, which is integrated into the medium pipe and can take a displacement of 20 mm. Each compensation-section is made out of a pipe-section which does contain a stress-reducer and a standard pipe-section.

The stress-reducer is located in the center of the section. During the layout-step the appropriate gaps between stress reducers are calculated depending on the pipe dimensions, soil-coverage and operating temperature.

With system 4 the first heating-up of the system compresses the stress-reducer by 20 mm. When the limit stop is reached, the pipes start to deform elastically. At normal operation temperature they are under compressive stress. While cooling down elastic expansion reduces and finally a gap builds up in the stress reducer, again.

At installation temperature the system is completely stress-free. From a mechanical point of view the Lögstör 4 system is cold installed, however, it acts like a pre-stressed system.

The system 4 with the stress-reducing tubes is buried without further components, i.e. without expansion pads, fixed points or others. The trench may be backfilled immediately; pipe ends at locations where the pipe route is changing direction need to be buried prior to heat-up to enable the system to generate the required axial stresses.

The system 4 allows for independent pipe routing. In addition, laying technology does not impose restrictions on the sequence of construction. Especially pre-stressing and expansion pads are not needed anymore.

The system 4 is a rather recent development, which can offer advantages when used in combination with cold installation and frequent obstacles. In these situations cold installation with standard pipes is not useful, because the effort for compensation would be to high. Future will decide if the system 4 proves to be technically o.k. and economically competitive against other solutions of expansion compensation.

Advantage: The pipeline can be finished and buried completely; later excavation doesn't cause any stress-problems.

Disadvantage: The installed compensators call for additional expense; it is assumed that the compensators are less reliable than standard pipes.

5 Check Measurements at Cold Installed Pipes

Cold installation causes an extensive utilization of the mechanical reserves of the pipe-systems. Cold installation therefore reduces the safety margin between the layout-case and the breakdown of the pipe, which is included mathematically by the safety factor. Since load-reserves generally increase the service-life of the system, caution must prevail when the system's strength is utilized extensively. In Germany a comprehensive investigation-program was carried out [4,5], which proved by detailed calculations and experiments, that even cold installation of BPP still offers sufficient safety when the correct layout principles are applied. However, some particularities need to be considered of which some have been mentioned above and some will be shown in the following.

The investigations focus on control of the

- displacements
- stresses / strains
- safety against revolting

5.1 Stresses and Displacements

Over a testing-time of 3 years comprehensive measurements were performed at a DN 250 pipe. For this case a vertically laid pipe was used while the arrangement of pipes was not important for the measurements. The supply pipe was put on top and to this pipe attention was paid.

The test-route had a length of 376 m. It was equipped with 3 buried concrete cavities for measurement, in which were measured:

1. the axial displacement
2. stresses
3. the temperatures
4. radial shift as estimate on the danger of revolving and settling of the pipe.

The technical data of the test-route are provided in Table 5-1.

First of all, comprehensive calculations of the stresses were performed, which resembled the consequences of cyclic temperature variations, see Fig. 5-2. Here, the calculations are not repeated, but it is referred mainly to the lower diagram in Fig. 5-2. There, the end displacement of the expansion bend is marked which experiences the maximum displacements after preset temperature variations. The diagram shows the *extreme initial* displacement and the consequences of the following temperature variations.

Table 5-1: Technical data of the test route (D-Mannheim, Münchwalder Straße)

Operating conditions:

- hot water supply temperature:
maximum 140 °C (500 hrs per year)
min. 75 °C

- return temperature: approx. 50 °C
- operating pressure: 11 bar
- layout pressure: 16 bar
- fluid: Heating water
- No. of Stress cycles: 1000
Installation system: preinsulated bonded pipe system
complying with EN 253 standard 1
- nominal diameter: DN 250
- element for compensation: expansion pad

Mechanical Boundary Conditions:

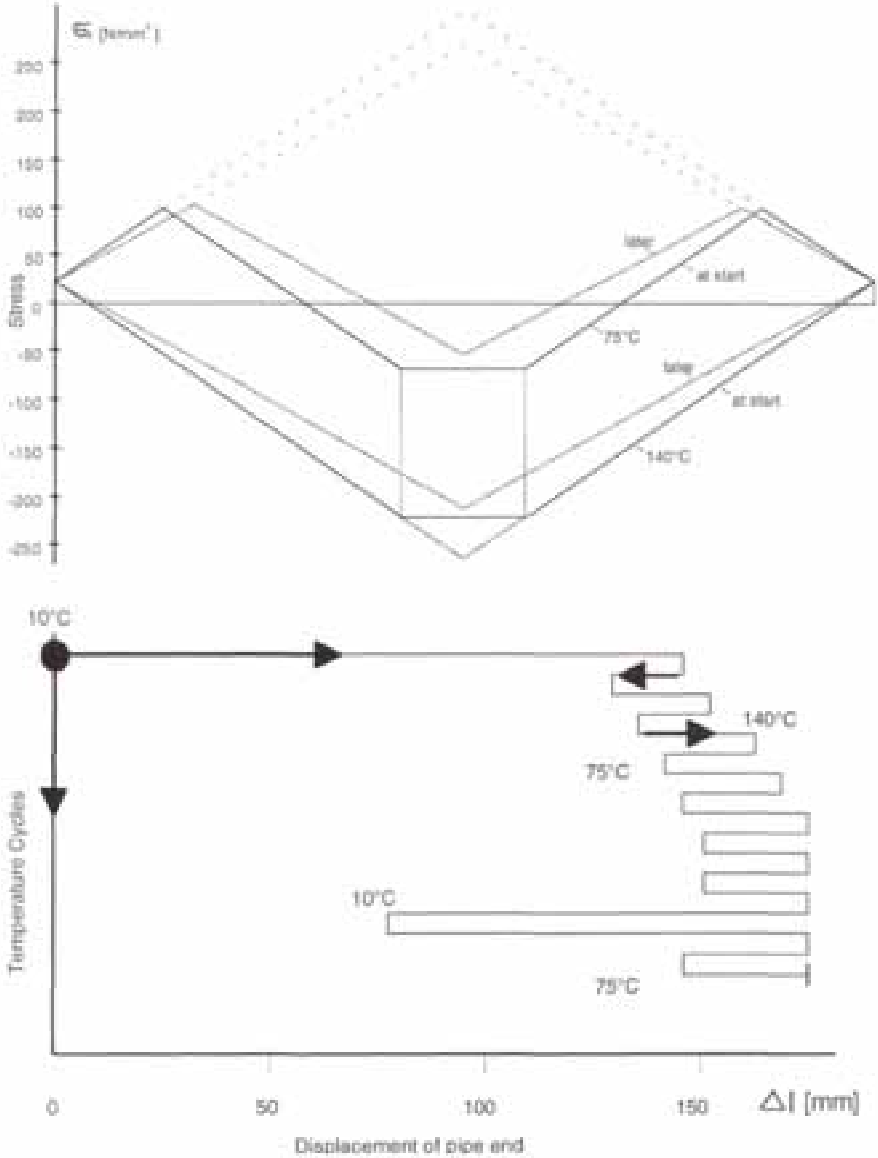
- laying technology: Cold Installation
- installation temperature: 20 °C
- supply pipe: on-top
- traffic load: SLW 60 complying with DIN

The results of the stress-calculations were cross-checked by experiment. During start-up of the pipe in November 1990 the pipe was heated-up by ΔT=120°C and the resulting stresses and end displacements were compared with the calculated values. First of all it could be ascertained, that the actual values were in agreement with the values calculated by means of the guidelines for design of AGFW.

The calculation methods for friction forces provided by these guidelines obviously meet the actual conditions. The values may be taken from Fig. 5-3.

The most interesting results of this test were generated by repeated measurements, i.e. displacement measurements of the pipe's end as a function of time. Since these results were new and in contradiction to common assumptions, they shall be presented here in 3 diagrams more comprehensively.

Fig. 5-2 Stresses and displacements due to varying temperature
Top: Stress-curves at different fluid temperatures
Bottom: End displacement at different fluid temperatures



In Fig. 5-4 the results of the measurement are marked, which were generated during the first year of measurements. The Figure shows the displacement as a function of temperature. All results lay inside the dark area. At low and at high temperature the scatter of recorded values is moderate. At medium temperatures intermediate data were recorded frequently; they were caused by phenomena of hysteresis.

The measured peak-displacement was substantially smaller than had been expected from calculation.

Even more surprising were the test results from the 2. year of measurement. They are presented in Fig. 5-5 where the area of results of the 1. year was included for reasons of comparison. The figure proves that the pipe has worked itself into a center-position, from which it executes only small expansional displacements. The position reached in the 2. year of measurement doesn't change in the subsequent time-period which could be assured by measurements over a 3. year.

It becomes visible in which periods the pipe approaches its limit positions, if one classifies the measurement-results of the first year by months, see Fig. 5-6. The pipe rearranges during the first 3 months after start-up (November, December, January) and then executes only minor movements. Indeed, it is necessary to bear in mind, that during these months the daily peak temperature stresses appear.

From these findings interesting consequences for the future technology of customer service connections could evolve. Of course, new customer service connections which are built concurrently to the main pipe, have to be designed with respect to the large displacements known from cold installation. But it would be possible to substantially reduce the effort of compensation at later customer connections which would be performed by the hot-tapping technique without shut down of the main pipe.

This result can not yet be assured without doubt. Of course, there is indication of a decreasing amplitude of the pipe's displacement from Swedish calculations, too [19], however there is also a contradictory test result [4]. This is the reason that the decrease of the displacement was not yet included in today's guidelines for design [1,3]. Final clarification is still necessary for this question.

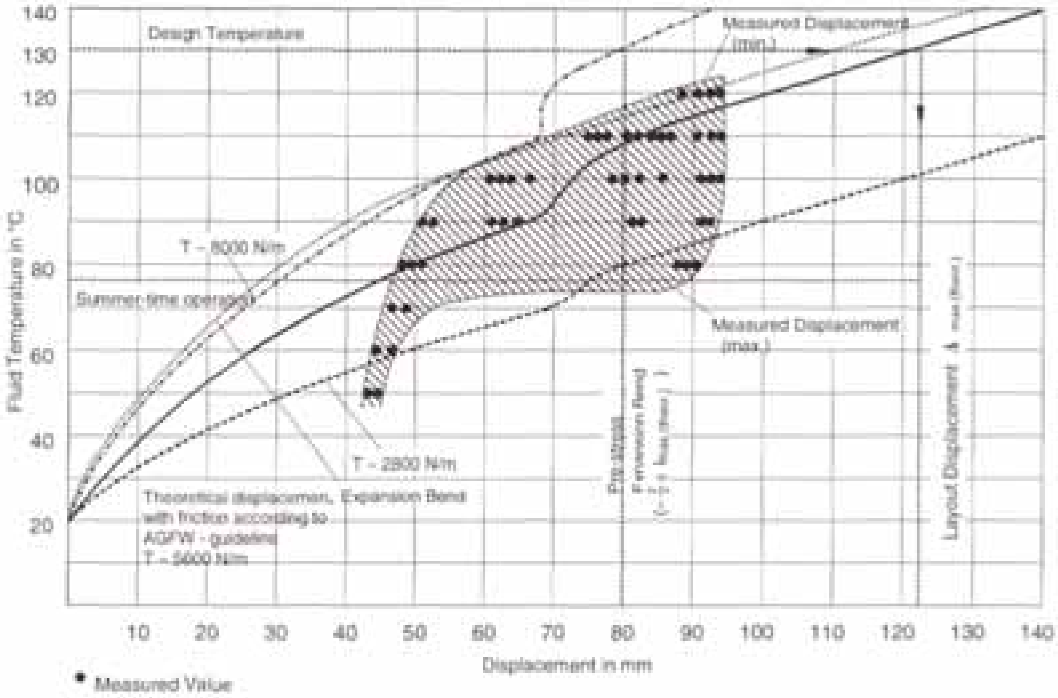


Fig. 5-3: Displacement-measurement in the 1. year after pipe start-up D-Mannheim, Mönchwälder Straße - measurement cavity No. 1

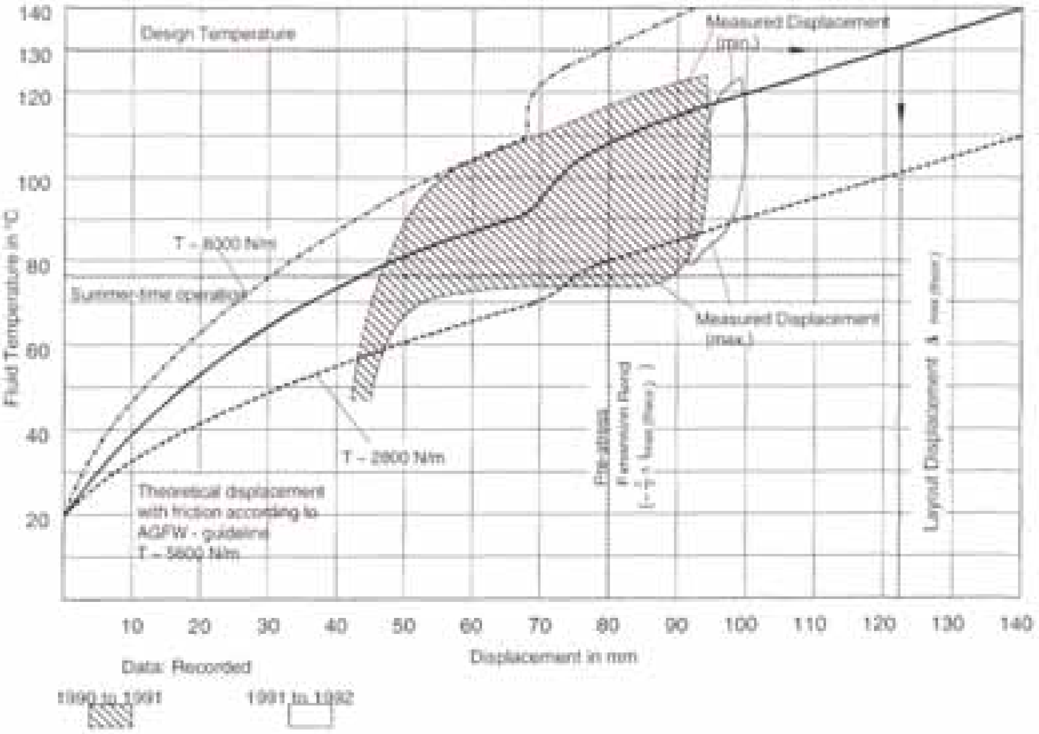
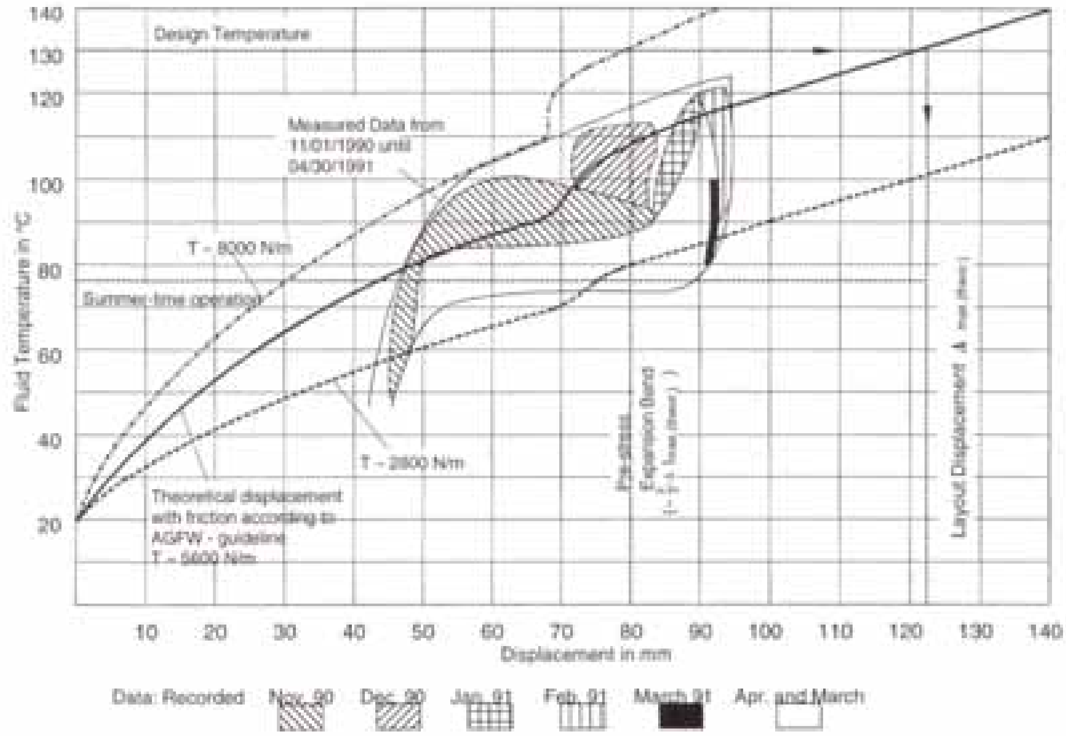


Fig. 5-4: Graph of the measurements for the 1. and 2. heating-season

Fig. 5-5: Strain-measurements during the 1. heating-season, classified by individual months



5.2 Safety against Revolting and Shifting

At a pipe exposed to axial compressive stress there is a danger of buckling. A buried pipe would buckle towards the direction of the least resistance, i.e. revolt upwards. From this stability analysis the minimum coverage is derived [2,3].

For conventional BPP - construction a minimum coverage of 0,35 m was sufficient. Since at cold installation higher compressive stresses occur an enlarged coverage is necessary. Table 5-7 lists the required coverages which need to be implemented at cold installation, if the indicated misalignment is anticipated and a safety factor of S=2 is required [4].

Table5-7: Minimum coverage at cold installation (completely restrained zone)

Normal diameter DN S	Misalignment [mm]	Required Coverage [m]
32	10	0,55
40	12	0,55
50	15	0,55
65	19	0,55
80	22	0,55
100	28	0,60
200	50	0,55
300	80	0,50
400	100	0,50

The computed values were compared with measurement-results as far as it was meaningful for the situation of pipe laying. For the test-pipe DN 250, which had been executed with a coverage of only 0,45 m, no vertical shift had been recorded which could have indicated a possible danger of revolting.

Also, the pipe's stability of position was examined after completion of construction and later during operation. The pipe's position was measured exactly at three measurement cavities and the displacements were recorded for a duration of approx. 2 years. After the pipe had been filled with water it settled down by 2 mm. In the following period no further shift was observed, although the pipe was operated at different temperatures. Therefore, it can be anticipated that district heating pipes are bedded safely in the street area and do not pose any danger on existing parallel pipes.

6 Operation of Cold Installed Pipes

For cold installed pipes in operation it's to be obeyed, that they are always compression-stressed. (In contrast, pre-heated pipes are nearly stress-free in summer-time). The state of stress is influenced by the operation temperature; the lower the operation temperature, the lower are the stresses in the cold installed pipe. For the time of working the pipe stresses are reduced by lowering the temperature as far as possible.

Attention must be paid to the elevated compressive stresses at cold installed pipes. At parallel pipe excavations one should take into consideration, that the pipe stands under compressive stress which is been balanced by reaction forces from the adjacent soil and therefore a danger of buckling is present. Furthermore, caution must be taken when the steel medium pipe is cut or hot taps are made when the pipe is still hot, see paragraph 6.2.

6.1 Parallel Excavations

Parallel excavations have to be distinguished whether they are done above or on the side of the buried pipeline.

At excavations done above the pipeline the soil-load decreases and so does the friction force. As a consequence, increased displacements may occur. The reduced soil pressure also raises the danger of revolting.

At parallel excavations on the side of pipes sufficient distances should be assured, if possible at least 1m. When necessary, special solutions need to be found. Excavations on the side of the pipe are assessed according to the method of excavation, the side distance and the depth. If the parallel excavation is braced correctly there is no danger of instability since the brace-support takes over the pressure function of the soil. In this case continuous trench-bracing is required. Excavation should start at the beginning of the expansion zone. If the parallel side-excavation next to the cold installed pipe is not braced a minimum distance of 1 m is sufficient when the trench is not deeper than the district heating trench itself.

The new excavation site should be so far apart from the district heating pipe that later settling does not influence the zone of the district heating pipe, i.e. outside the 60° settling-cone.

At deep excavations parallel to the district heating pipe special investigations may become necessary.

Numerically, these relations are outlined in Fig. 6-1 [4]. The upper diagram shows the length over which the cold-installed pipe can be fully excavated when originally designed to $\Delta T=120$ K. The values are based on a safety factor of $S=2$. For comparison the permissible values for $\Delta T=120$ K are added in the same figure.

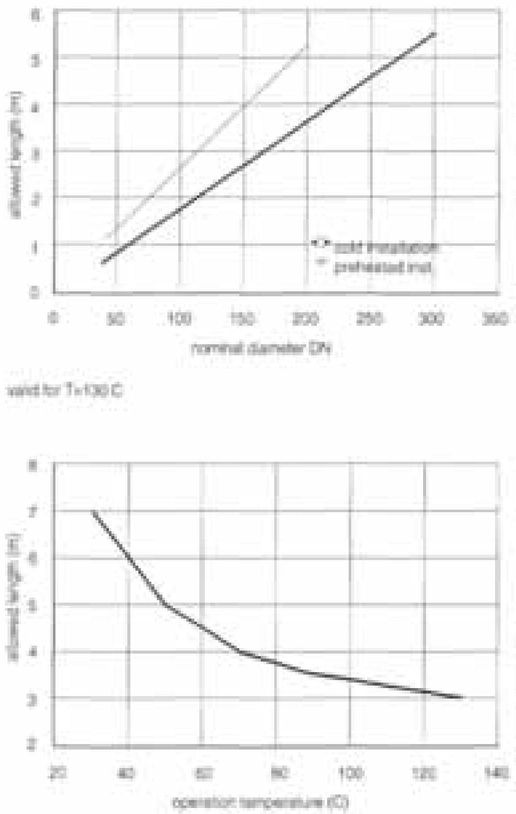
Since the permissible length of parallel excavations is strongly dependent on temperature the lower diagram of Fig. 6-1 displays the permissible length for a specific pipe diameter (DN 150) with temperature as a parameter. The additional x-axis accounts for preheated pipes.

6.2 Repairs

Repairs of the medium pipe may become necessary in the zone of completely restrained pipe as well as in the expansion zone. During excavation the cooling rate for the pipe has to be known as it may change the pipe's temperature during the time of construction and, as a consequence, displace the pipe ends. If the pipe is cut close to the compensation element - inside the expansion zone - the pipe ends must be fixed with a special clamping device so that they can be welded together later on.

If the exchange of a pipe section is needed inside the restrained zone of a cold installed pipe it can be done more easily than with a thermally pre-stressed pipe. In practice the new piece of pipe is installed when it is still at ambient temperature and the pipe is then put in operation again. Prior to pipe cutting the mechanical layout of the service connections has to be considered.

Fig. 6-1: Permissible side excavation of cold installed pipe
Top: Length of excavations in comparison to pre-heated laying
Bottom: Temperature effect for a pipe DN 150



valid for T=130 C

valid for DN 150

6.3 Hot Tapping (Drilling) of the Pipe During Operation

When drilling into a pipe in operation in order to get new service connections, the stress conditions need to be considered. Branches may be welded to bigger main pipes without reinforcement of the tapped pipe (Value drawn from past experience for cold laid pipes: The branch must be smaller at least 2 steps in nominal diameter).

At nearly equal pipe-diameters the main pipe has to be reinforced so that pipe forces do not deform the section inadmissibly.

Some utilities admit to drill only at medium sized pipes, for instance from DN 80 to DN 300. In Finland, no limitation of this kind exists. In Sweden, drilling is handled restrictively.

7 Construction-Times, Construction-Costs

Cold installation reduces construction costs. A detailed calculation of the savings is difficult to do since construction costs are always a result of a specific construction site and each site has it's unique cost relations. It gets even more complicated when costs are compared between different companies and especially involved for international comparisons. There are certain similarities between countries, e.g. Sweden [12], Germany et. al., according to which the ratio of excavation/backfilling to pipe installation as civil engineering costs for BPP-systems are in the order of 60 to 40; for further detail please refer to Appendix 2 and 3. On the other hand this ratio is almost inverted in Finland to 40 over 60, where details are provided in [13]. Probably the lower civil engineering costs in Finland are caused by a high share of construction under unpaved surfaces.

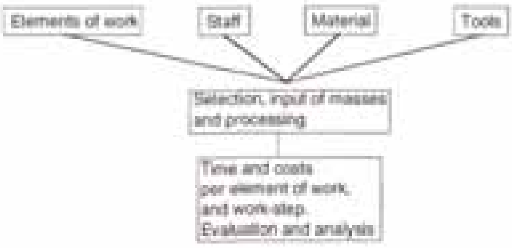


Fig. 7-1: System for documentation of time needs and cost calculation

In Germany (Mannheim) very detailed investigations of actual construction times were performed by means of which one is able to rank the different construction techniques from a more universal point of view. The works both for workers as well as for machines were divided into elements and simulated with computer (see scheme in Fig. 7-1, more background information in [5]). The calculation model was tuned by comparison with actual construction projects. Cost comparisons are started with the creation of a specific construction case. The calculation solves for the most cost-efficient construction-technique.

In a number of simulation runs the experience was verified that reduced construction times lead to lower construction costs. Obviously, shorter construction time means a better utilization of resources.

Also the cold installation was analyzed for single-costs and the results compared to those of the common thermal pre-heating laying technology. The results are presented in the following.
The cost analysis were performed using a model construction site, which was rated typical by several district heating utilities, see Fig. 7-2. Nominal diameters of DN 65 up to DN 100 were prevailing whereas the length of pipe route totaled 500 m.

The cross sections of the trench for the analyzed laying technologies

- Variant 1: thermally pre-stressed
- Variant 2: cold-installed

are presented in Fig. 7-3. The figure shows the braced trench on the left; variant 2, on the right side of the figure, could be done by proceeding day-by-day, so-called single-day-construction, where no trench side support was required. Day-by-day proceeding means, that the route was divided into short length segments for each of which excavation, pipe laying and backfilling could be done during a single day. Day-by-day proceeding becomes feasible, if the construction site is well prepared (asphalt layer is cut, pipes are welded and checked for leak-tightness) and also finishing work-steps are permitted (reinstallation of the street's wear layer). Here, the single-day-construction lengths were about 40 m; also, a single-day progress of 100 m for DN 80 has already been accomplished, see [5].

The single-day-construction technique responds to the time-limited stability of the trench walls by reducing time and thereby saving the braces to support the trench. The soil remains stable for almost always a minimum duration of one day in which the pipe is buried and the trench backfilled.

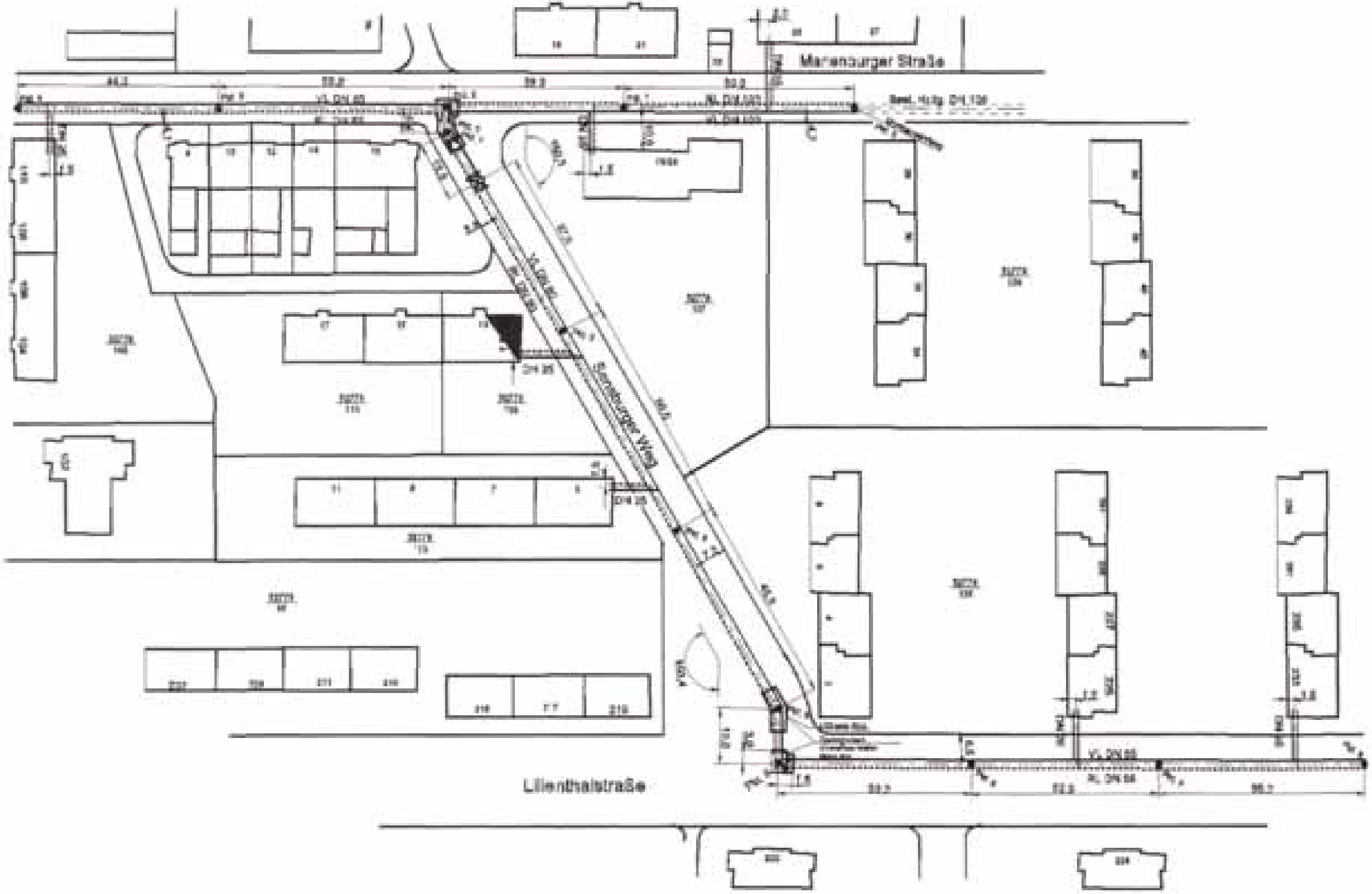


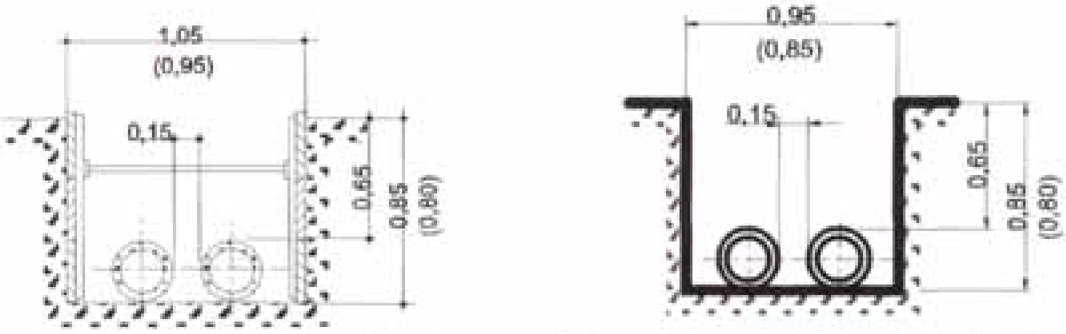
Fig. 7.3 Plan of the construction site

Characteristics:

- pipes side by side
- braced trench
- preheated

- non braced trench
- cold installation
- single-day construction site

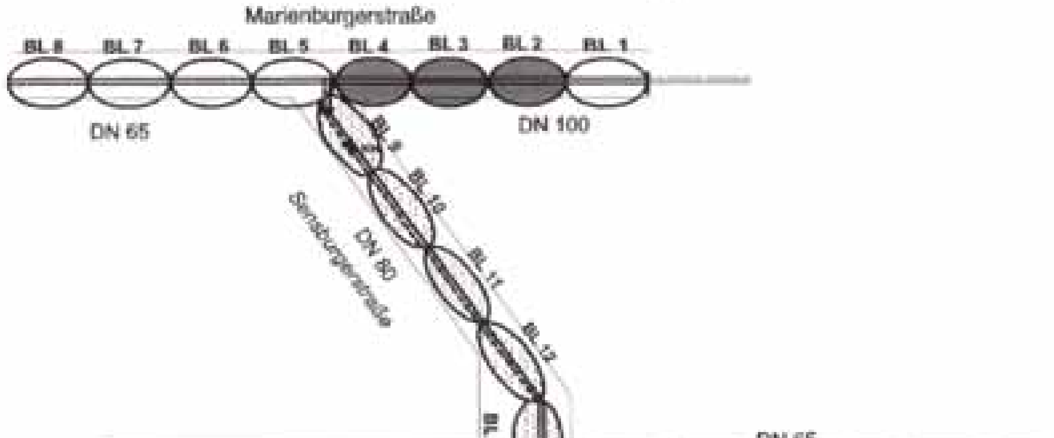
Fig. 7-3: Cross section of trenches for cost analysis



The calculation of costs of the variant 1 anticipated a subdivision into 3 construction packages, while the variant 2 was divided into 19 single-day-construction-sites, see Fig. 7-4.

The complete construction-schedule for both variants is found in the Appendix.
Variant 1, the installation with pre-heating, requires an overall construction- time of 55 days, whereas variant 2, cold installation in day-by-day construction needs an overall completion-time of 36 work-days.

Fig. 7-4: Plan of variant 2, stages of construction



Both variants were estimated with the above described system of cost calculation. The result is included in the survey which is found in the appendix 1 of this report.

As an overall result it can be concluded: Cold installation of pipes can be done more quickly and more cost-efficient than the installation by thermal pre-stressing. The construction-time reduces to about 67% and the construction costs total about 81% of those needed for pre-heating.

Construction-Timetable (Calculation based on ZUKS)

Marienburger Straße Length of pipe route 510m , nominal pipe diameter DN 100/80/65
Phase I : Construction and Laying Technology of year 1988
(Horizontal Laying - with bracing - three-step construction - sand - pre-heating)

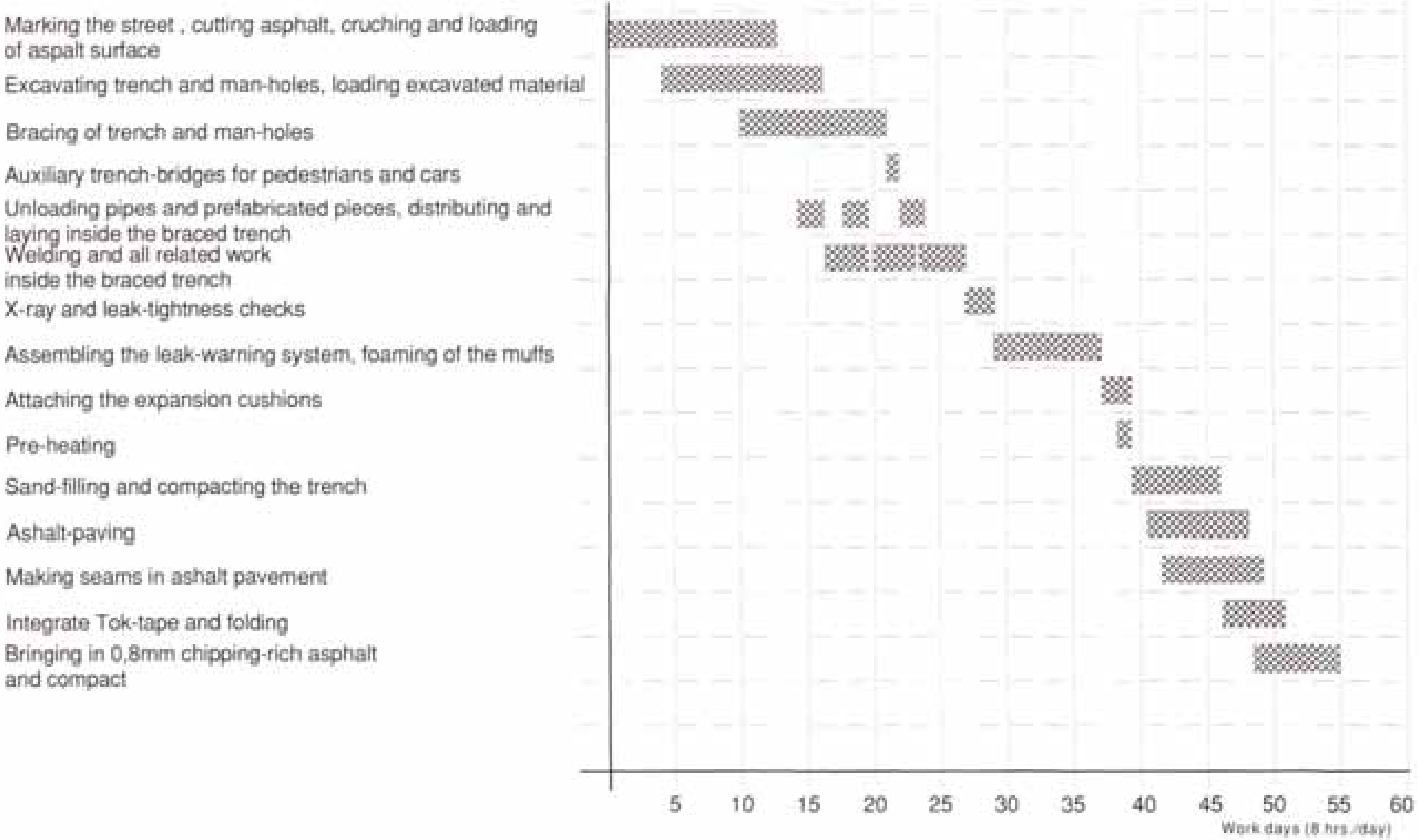


Fig. 7-5: Time-schedule for installation with pre-heating (variant 1)

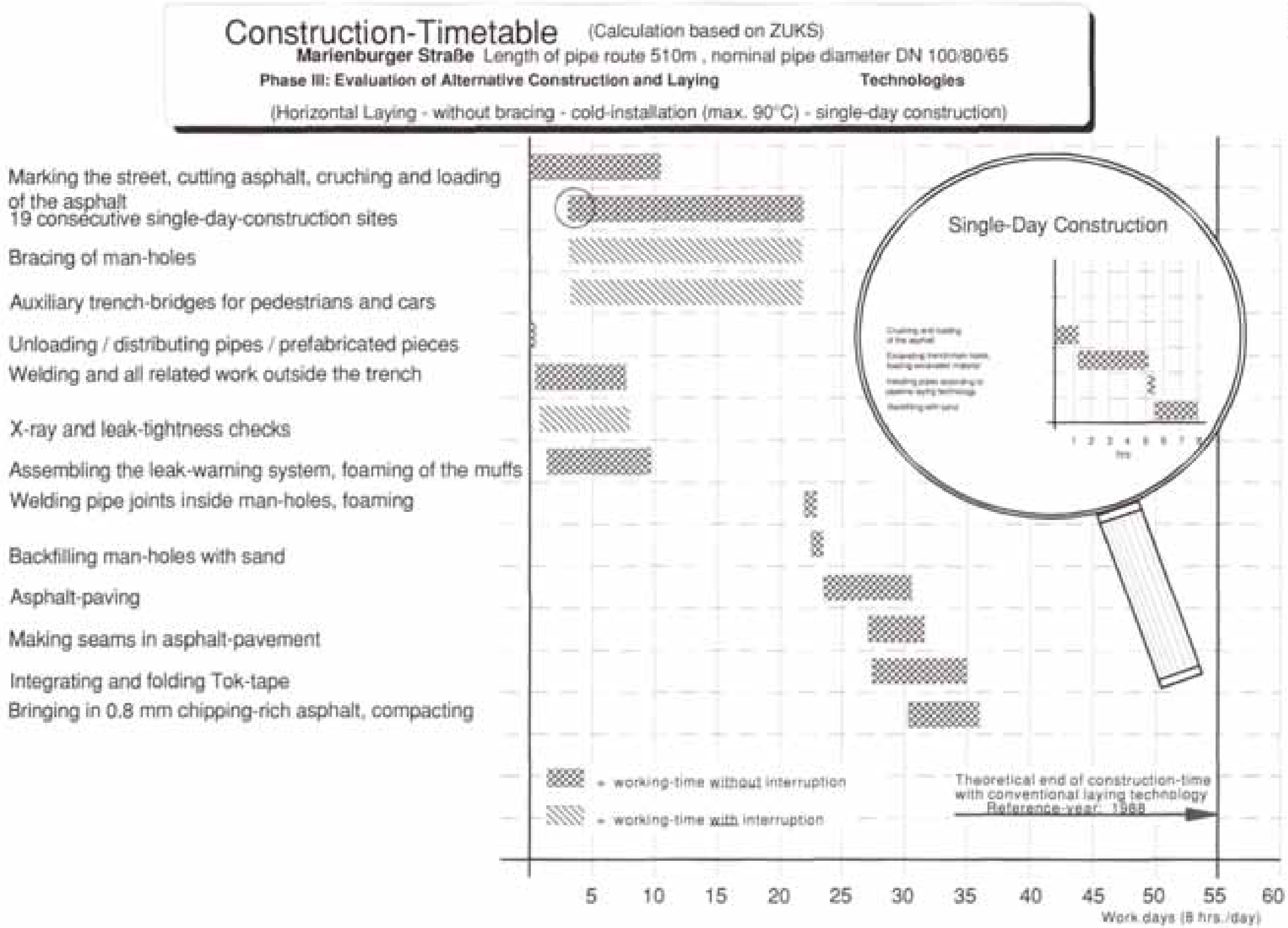


Fig. 7-6. Time-schedule for cold installation (variant 2)

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Tebodin B.V, Den Haag 1997

Definitions

Cold installation:	Cold installation is a pipe laying technique without pre-expanding (e.g. by preheating). Additionally, cold installation (in its modern form) means, that the 0,2% - yield strain is not limiting the mechanical layout but pipes are designed according to a fatigue analysis.
Present conventional laying:	Today the installation is done most frequently by preheating.
Preheating:	Preheating is a special method to expand the district heating pipe. The preheating can be accomplished different ways, e. g. with hot water, electrically, with low pressure steam and others.
Compensation for Expansion, Compensator, Strain Reducer:	A compensation-element takes the thermal expansion of a section of the district heating pipe.
Displacement:	The displacement is the shift of a definite pipe location, e.g. of a pipe bend, due to thermal expansion of the piping (in contrast to the material strain).

Appendices

(Originals - not translated)

Appendix 1:	Comparison of Cost Calculations – MVV,D - Mannheim
Appendix 2:	The Cost Elements of Pipeline Construction in Sweden
Appendix 3:	The Cost Shares of Civil Engineering and Pipeline Construction as Parts of the Overall Costs, 4 German Utilities report.

Appendix 1: Comparison of Cost Calculations- MVV, D - Mannheim

Cost Comparison

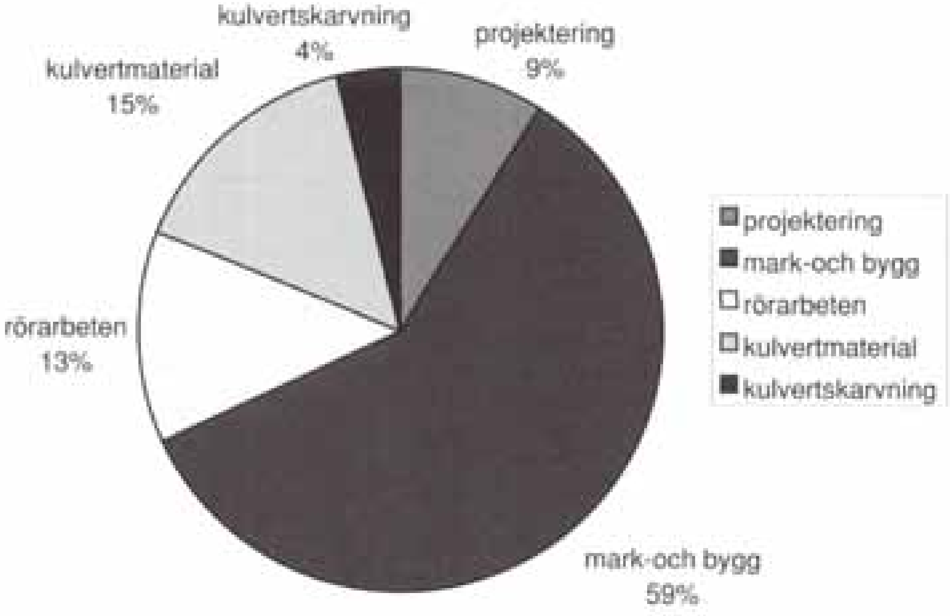
(Thermal Pre-stressing, Cold Installation (Variant 1, Variant 2))
Marienburger Straße, Mannheim
pipe route length 510m, nominal diameter DN 100/80/65

	Variant 1	Variant 2
Tiefbau		
Aufbruch von Verkehrsfläche 0 - 10 cm Stärke	*12.196,37 DM*	*12.144,79 DM*
Grabenaushub in Maschinenarbeit bis1,25m Bkl.3	15.435,12 DM	11.989,18 DM
Montagegrubenaushub, T. 0- 1,75m, Bkl. 3-4	1.708,58 DM	1.708,58 DM
Aushub zwischenlagern	13.345,17 DM	12.074,00 DM
Stab. Sand liefern, einbauen	-	-
Sand liefern, einbauen u. verdichten	17.065,77 DM	15.598,23 DM
Feinplanum herstellen	1.630,47 DM	1.494,00 DM
Summe Aushub und Einfüllen	*49.185,11 DM*	*42.863,99 DM*
Waagerechter und senkrechter Verbau mit Holzdielen	*20.856,23 DM*	*4.372,71 DM*
Fußgängerbrücken, Behelfsbrücken	*6.029,03 DM*	*2.873,40 DM*
Bit. Tragschichtmat. lief. u. einbauen	20.036,93 DM	18.125,55 DM
Tokband liefern, einbauen an den Kanten	6.984,99 DM	6.984,99 DM
Bit. Deckenbelag einschneiden, abbrechen, aufladen, abfahren (Überlappung 15 cm)	7.072,57 DM	7.072,57 DM
Splitreicher Asphaltbeton 0-8mm liefern, einbauen u. verdichten	13.757,36 DM	12.277,00 DM
Summe Straßenherstellung	*47.851,85 DM*	*44.460,11 DM*
Summe Tiefbau	**136.118,59 DM**	**106.715,00 DM**
Rohrbau		
Rohre abladen	338,17 DM	338,17 DM
Rohre verteilen, verlegen	4.435,45 DM	3.000,00 DM
Rohrschnitte herstellen	305,35 DM	305,35 DM
Fertigteile u. Fertigbögen einbauen	213,43 DM	213,43 DM
Klöpperböden, Anschweißstutzen montieren	378,94 DM	378,94 DM
Kunststoffmantel abtrennen	221,72 DM	221,72 DM
Rund- und Segmentschweißung	8.047,06 DM	7.720,25 DM
Stutzenschweißung	128,81 DM	128,81 DM
Stahlrohrbogen, Reduzierstück einbauen	664,04 DM	664,04 DM
Summe Rohrbau	**14.732,97 DM**	**12.970,71 DM**
Rohrlieferung u. Nachisolierung		
Rohre liefern	*45.522,30 DM*	*45.522,30 DM*
Festpunktbrücken)*	-	-
Montage Kontrollsystem	3.301,21 DM	3.301,21 DM
Muffen ausschäumen	5.167,12 DM	5.167,12 DM
Montage Dehnungszonen	6.041,19 DM	-
Summe Nachisolierung	*14.509,52 DM*	*8.468,33 DM*
Summe Rohrlief. u. Nachisolierung	**60.031,82 DM**	**53.990,63 DM**
Warmfahren)*	**2.841,00 DM**	-
Baustelleneinrichtung)**	**6.000,00 DM**	**5.000,00 DM**
Gesamt	***219.724,38 DM***	***178.676,34 DM***

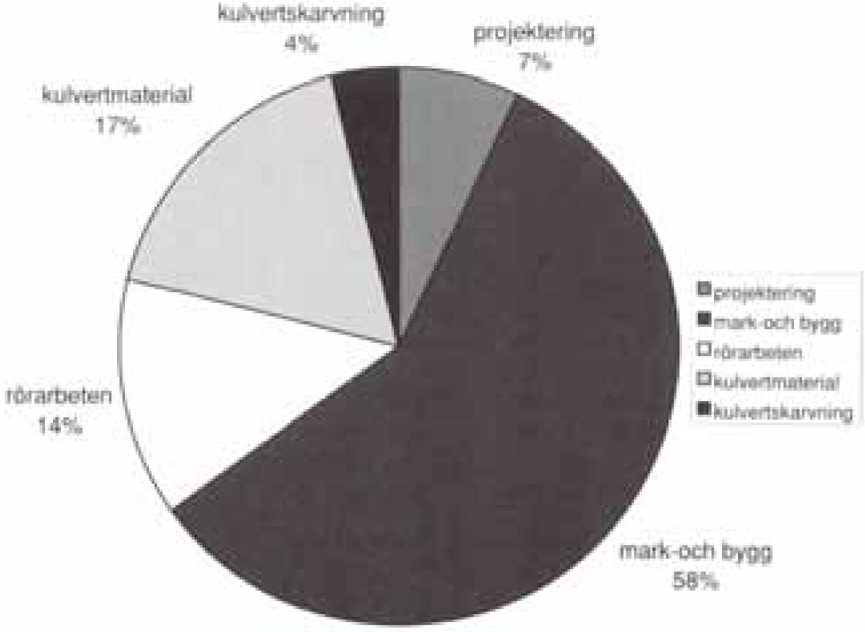
)* estimates based on MVV-invoice
)** estimated to 4% of excavation and pipe work

Appendix 2: The Cost Elements of Pipeline Construction in Sweden

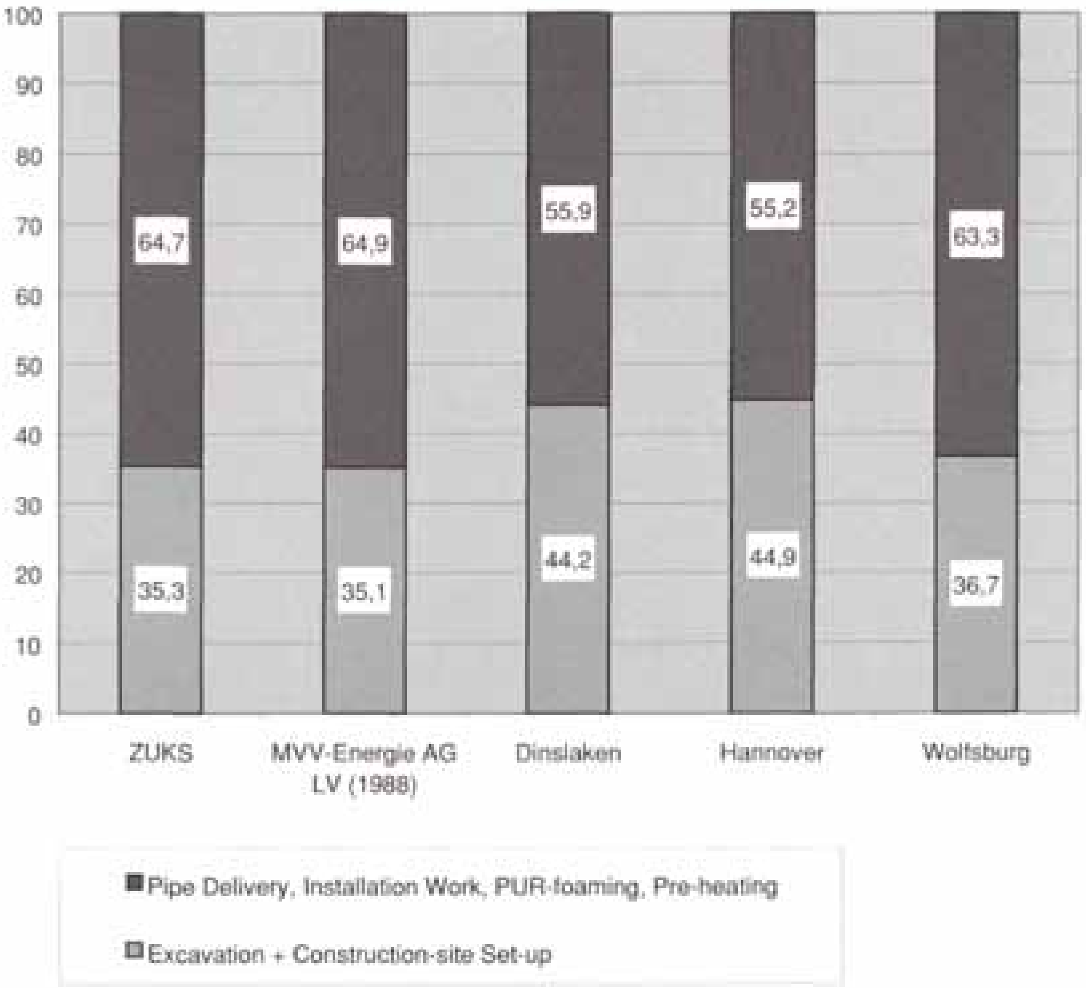
a) Construction-site in the city-centre



b) Construction-site in a suburban area



Appendix 3: The Cost Shares of Civil Engineering and Pipeline Construction as Parts of the Overall Costs, 4 German Utilities



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