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BEND-PIPES

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Programme of Research, Development and Demonstration on District Heating

Bend-pipes

Dealing with the subject:

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Contents

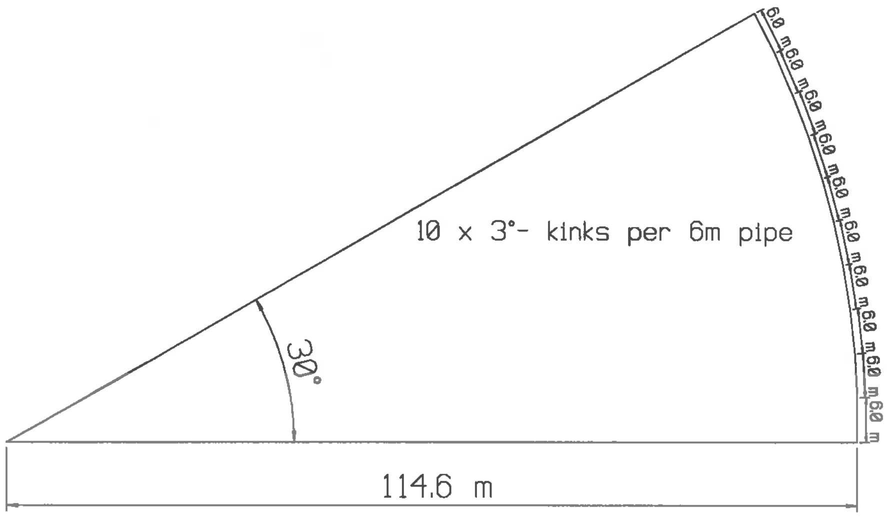
1. Introduction

Bend-pipes are components of pre-insulated bonded pipes made from straight pipes by bending. Bend-pipes have clearly larger radii in comparison with bends:

- Bend-pipe radius > 50 x $D_{steel\ pipe}$
- Bend radius = 1,5 to 2,5 x $D_{steel\ pipe}$

The use of bend-pipes is particularly advisable when the best possible lay out requires a large radius. If for example the bend of a street is to be followed, bend-pipes offer a lay out possibility which means the lowest expenditure with regard to installation lengths, construction site and compensation expenditure with the corresponding radius.

At the realisation of changes of direction with pre-insulated bonded pipes normally 3° kinks are applied for small angles. Larger changes of direction (e.g. 30 °) can be realised without statical test by applying several 3 ° kinks with a minimum distance of 6 m. However, only relatively large lay out radii (R ~ 114.6 m) can be created this way (see picture 1-1).



Picture 1-1: Example of a 30 ° change of direction with 10 x 3° kinks per 6 m of straight pipe, resulting lay out radius R = 114.6 m.

This radius is independent of the pipe dimension. At DN 100 the installation radius is realised with 3 ° kinks for about 1000 * $D_{steel\ pipe}$ compared with a minimal bending radius at DN 100 of 15 m, that is 130 * $D_{steel\ pipe}$.

Bends frequently cannot be used for such lay out situations for the very high loads on the little radius of the bend. Bend-pipes on the other hand behave mechanically almost like straight pipes, the load on the bend-pipe is hardly higher than in the straight pipe. Bend-pipes are therefore virtually ideal installation elements for changes of direction between 15 ° and 70 °.

The admissibility of bending at cold installation is differently assessed in Germany. At field try outs at Fernwärmeversorgung Dinslaken [1] with continuous flows in cold installed 3 ° kinks a temperature lift of 120 K was measured. Further parametric FEM calculations proved, that at this temperature level only installations without kinks are permitted. Changes of direction then had to be created with bend-pipes. According to assessments of Rumpel [2] the opinion should be that cold installed kinks with segment angles up to 5 ° certainly are able to resist the full temperature lift without larger deformations.

Bend-pipes are no standardised components and are therefore differently laid out and manufactured, resulting in different smallest radii for bend-pipes for different manufacturers. The differences in permissible bending radii depend on one hand on calculation methods, and on the other hand on applied methods of manufacturing. To get a summary of the backgrounds of the offered bend-pipes, the manufacturers became a questionnaire on bonded pipes with the topics

- Laying out of bend-pipes,
- Manufacture of bend-pipes,
- Economy of bend-pipes.

In the appendix the questionnaire used is enclosed.

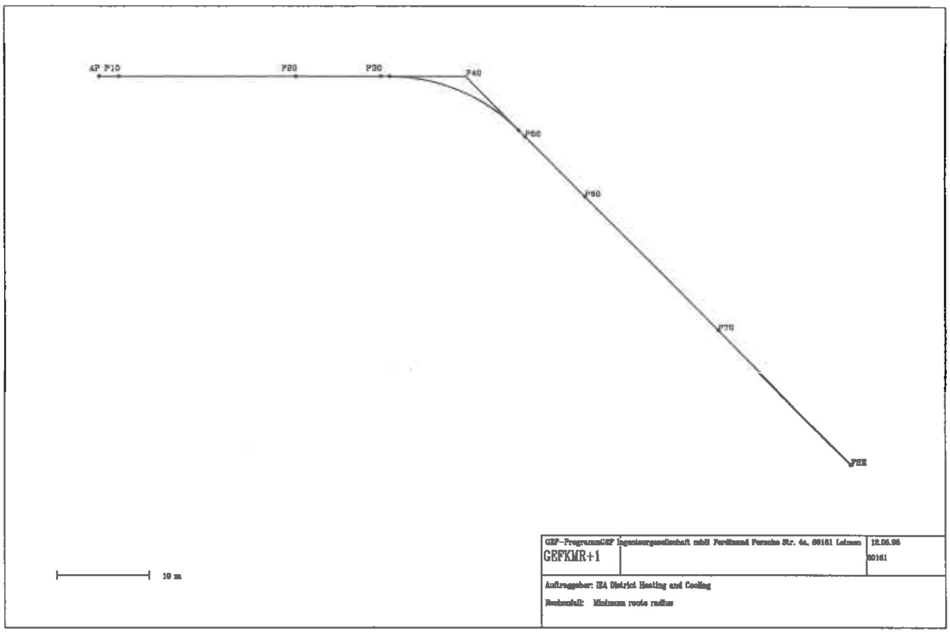
The following explanations are based on the evaluation of this questionnaire which was answered by the manufacturers:

- Pan-Isovit (Germany),
- ABB-I.C. Moller (Denmark),
- Tarco (Denmark),
- Powerpipe (Sweden),
- Isoplus (Austria) .

2. Laying out of bend-pipes

The laying out of bend-pipes is possible with smaller curve radii in the vision of the planning engineer than shown in manufacturer catalogues. This fact will be presented briefly in an example.

For a pipeline with a dimension DN 300 a 45 ° change of direction, like presented in picture 2-1, shall be created. The example is selected that no extreme loads appear, like at cold installation.

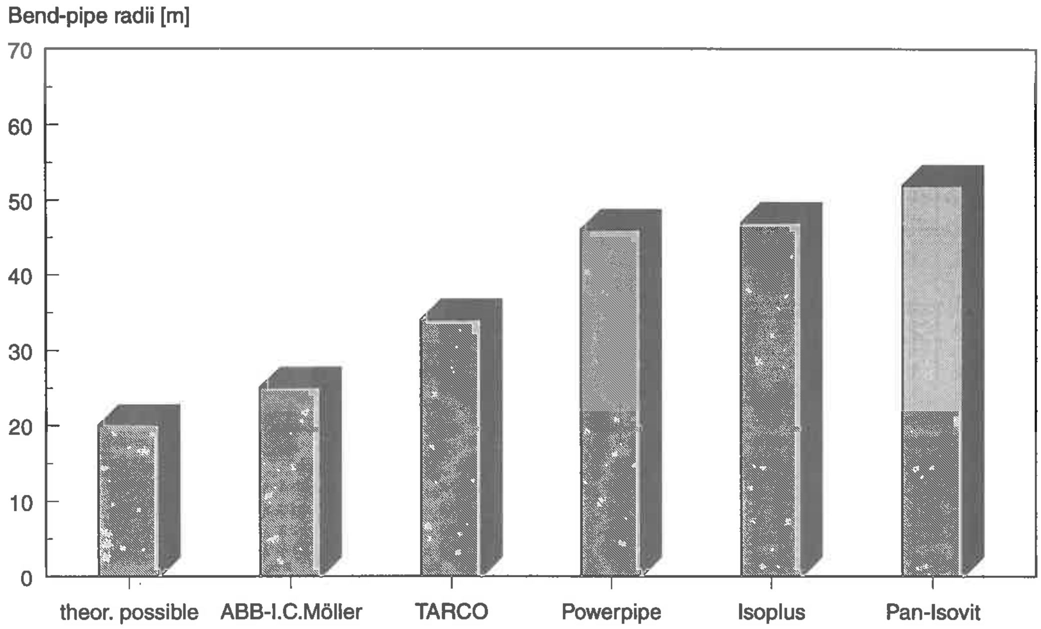


Picture 2-1: Example for one 45 ° change of direction of a DN 300, calculated with GEFKMR [4]

Calculations [4] (see appendix B) submit a maximum axial stress of approx. 180 N/mm², this value is smaller than the one permitted according the AGFW guideline in Germany with a value of 190 N/mm².

A minimum radius of R = 20 m is allowed for the bend-pipe, in which the critical value for the laying out is the compression of PUR foam. The applied pressure is 0.126 N/mm² for the example. The allowable compression is 0.15 N/mm².

In the manufacturer catalogues information for the smallest allowable radii vary depending on manufacturer and method of installation for a DN 300 bend-pipe between R = 25 m and R = 52 m (cf. picture 2-2). To clear the discrepancy between the theoretically possible bend-pipe radii and the radius offered by manufacturers the calculations of the example was presented to the manufacturers and they were asked for their criteria for laying out. The answers of the manufacturers on the lay out of bend-pipes are presented in the following.



Picture 2-2: Comparison of theoretically possible bend-pipe radii and the minimal bend-pipe radii at DN 300 indicated by the manufacturers.

TARCO

The permitted compression in the PUR foam is indicated by TARCO as criterion for horizontally installed bend-pipes.

In the manufacturer catalogue of TARCO is added that the permissible bend-pipe radii (see table 2-1) are calculated to sufficiently counter the force of the soil to avoid lateral instability.

DN	Cold Laying R (m)	Compensation R (m)	Pre-tensioning R (m)	Self pre-tensioning R (m)
32	13	19	10	19
40	13	19	10	19
50	14	21	11	21
65	14	21	11	21
80	16	23	12	23
100	16	23	12	23
125	18	25	14	27
150	20	27	15	30
200	23	29	17	33

DN	Cold Laying R (m)	Compensation R (m)	Pre-tensioning R (m)	Self pre-tensioning R (m)
250	25	33	19	37
300	28	34	21	41
350	28	35	21	42
400	31	39	24	46
450		39	24	
500		46	29	
600		94	56	

Table 2-1: Smallest bend-pipe radii at different methods for installation in accordance with manufacturers catalogue of TARCO.

In table 2-1 the different methods for installation of TARCO are defined:

- Cold laying: Distribution networks up to DN 400 with operating temperatures up to 90 °C and operating pressure up to 16 bar.
- Compensation: At operating temperatures higher than 90 °C is the length of installation limited and expansion possibilities have to be provided (I bend, Z bend, U curves and axial compensators).
- Pre-tensioning: At operating temperatures higher than 90 ° C and at exceeding the maximum length of installation the pipe line must be pre-tensioned. The pre-tensioning is carried out thermally or with one time compensators.
- Self pre-tensioning: At operating temperatures higher than 90 ° C and at exceeding the maximum length of installation is realised by reaching the yield stress of the service pipe at the start of the operation.

Note the concept of "cold laying" used in this report. Cold installing is used like TARCO defines "self pre-tensioning". The indicated bend-pipe radii only apply to the pipe actually bent. Straight ends of respectively 2,5 m at pipes < DN 200 and 1,5 m at pipes > DN 200 have to be added, which increase the radius of the lay out.

In case of laying out with pre-tensioning TARCO mentions a smallest bend-pipe radius for a dimension DN 300 of R = 21 for which the calculations are practically identical to the example. However the pre-defined lay out example did not consider the necessary pipe end compensation and a installation radius of R = 34 m is therefore the result.

Asked for examples of installed pipelines with large dimensions and small trace radii, TARCO mentions:

- DN 900 R = 42 m Operator: Iceland
- DN 800 R = 40 m Operator: Iceland

At vertically installed bend-pipes is the approach, according to TARCO, the same as for horizontally installed bend-pipes.

ABB- I.C. Moller

ABB indicates the highest allowable earth pressure as criterion for horizontally installing bend-pipes .

The manufacturer catalogue mentions the resulting smallest bend-pipe radii for the thermally pre-tensioning installation method, compensation bends and one time compensators (E-sockets), see table 2-2. The radii are indicated depending on the height of the cover or the earth pressure. Considered should be that in the table the projection radius is given and which is larger for manufacturing reasons because of the straight pipe-ends.

type bendpipe	steel pipe outside dimension [mm]	p = 0,05 h = 0,4		p = 0,058 h = 0,5		p = 0,065 h = 0,6		p = 0,073 h = 0,7		p = 0,09 h = 0,8	
		V° max.	R_p	V° max.	R_p	V° max.	R_p	V° max.	R_p	V° max.	R_p
bendpipe production at work	26,9		5,9		5,1		4,6		4,1		3,8
	33,7		7,6		6,6		5,9		5,3		4,8
	42,4		7,7		6,9		6,2		5,5		5,1
	48,3		9,3		8,0		7,2		8,0		7,3
	60,3		12,0		10,0		9,0		8,0		7,3
	76,1		13,0		12,0		10,0		9,2		8,3
	88,9		15,0		13,0		12,0		10,0		9,6
bendpipe production at factory	114,3	38	18	38	18	38	18	38	18	38	18
	139,7	34,5	20	40,5	17	43	16	43	16	43	16
	168,3	28,5	24	33	21	36	19	40,5	17	46	15
	219,1	23,5	29	27,5	25	30	23	34,5	20	38	18
	273,0	21	33	24,5	28	27,5	25	31	22	33	21
	323,9	17	40	19,5	35	22	31	24,5	28	27,5	25
	355,6	17	40	20	34	23	30	25,5	27	27,5	25
	406,4	13	53	15	46	17	40	19	36	21,5	32
	457,2	12,5	55	14,5	47	16,5	42	18	38	20	34

type bendpipe	steel pipe outside dimension [mm]	p = 0,05 h = 0,4		p = 0,058 h = 0,5		p = 0,065 h = 0,6		p = 0,073 h = 0,7		p = 0,09 h = 0,8	
		V° max.	R_p	V° max.	R_p	V° max.	R_p	V° max.	R_p	V° max.	R_p
	508,0	13	53	15	46	17	40	19	36	21	33
	558,8	13	53	13,5	51	17	40	19	36	21	33
	609,6	10,7	64	12,5	55	14	49	15,6	44	17	40

P : soil pressure in N/mm ² per pipe
H : vertex cover (m)
V ° $_{Max.}$: Max. Permitted angle per 12 m of pipe
R_p : Min. projection radius (m) V ° $_{Max.}$
R_p refer to the centre line of the installation

Table 2-2 : Minimal bend-pipe radii depending on the covering according to ABB, not for cold laying.

The radii at cold installation must be increased according the formula given by ABB.

New Radius = table value x ($Dt_{cold\ laying}$ / 90)

with $Dt_{cold\ laying}$ = $T_{operating}$ - 10 ° C

and $T_{operating}$ > 100 ° C

If the results for the smallest bend-pipe radii of ABB at a cover of 0,8 m (R = 25 m) are compared with the results of the example calculation (R = 20 m) there is no serious difference.

Furthermore should be considered that the real bending radius due to the straight ends of the pipe is smaller than the value of the installation radius mentioned by ABB. The criterion for installation, the "highest allowable earth pressure", however can not be comprehended. A discussion of these uncertainties is presented at the end of this section.

As executed example for installing bend-pipes of larger dimensions with a small bend-pipe radius ABB presents a DN 650 pipeline (outside diameter 660 mm) with a radius R = 90 m.

ABB states the "highest allowable earth pressure" also as lay out criterion for vertically installed bend-pipes. In addition if is pointed out by the manufacturer that by using bend-pipes at changes of level the covering vertex and the lateral instability have to be considered. A fundamentally smaller bending radius is realised compared with the horizontal laying according to the details of ABB.

From our point of view this argumentation is contradictory, because lateral instability actually requires a larger radius.

Powerpipe

Powerpipe indicates as installation criterion for bend-pipes horizontally at small dimensions

- highest allowable earth pressure

and at large dimensions

- permitted compression in the PUR foam and the
- permitted circumferential stress in the steel service pipe

Table 2-3 presents the largest change angles and smallest radii in the manufacturers prospect.

dimension	l = 12 m		l = 16 m	
	maximum change angle	minimum radius [m]	maximum change angle	minimum radius [m]
DN 25 - 80	35°	20,0	-	-
DN 80 - 150	35°	20,0	-	-
DN 200	25°	28,0	-	-
DN 250	20°	34,0	28°	33,0
DN 300	15°	46,0	22°	42,0
DN 400	15°	46,0	17°	54,0
DN 500	-	-	10°	92,0
DN 600	-	-	8°	115,0

Table 2-3: Maximum change angles and minimum radii for bend-pipes according to Powerpipe.

Powerpipe does not say whether the minimum bend-pipe radius is determined by production or by installation. Compared to the DN = 300 with R = 20 the smallest bend-pipe radius at DN 300 of R = 42 m indicated by Powerpipe is fundamentally larger.

As executed examples of particularly narrow installation radius at large dimensions were indicated by Powerpipe:

- DN 600 R = 115 m — operator: Södertörn Fjärrvärme
- DN 500 R = 100 m — operator: Halmstadt Energi
- DN 400 R = 50 m — operator: Helsingborg Energi

Isoplus

As lay out criterion for installing horizontally bend-pipes Isoplus refers to

- the highest allowable earth pressure,
- the permitted compression in the PUR foam and
- the permitted circumferential stress in the steel service pipe.

Table 2-4 lists the smallest bend-pipe radius mentioned in the manufacturers catalogue, at a permitted tension of the steel pipe of $t_{permitted}$ and an earth pressure of $p = 0.04$ N/mm ^{2} after the formula

$$R = A \cdot \sigma / p \cdot D \qquad (1)$$

with A. . . Steel pipe cross section (mm ^{2})
σ. . . Permissible strain (N/mm ^{2})
p. . . Earth pressure (N/mm ^{2})
D. . . HDPE casing diameter (mm)
L. . . Pipe length (m)
R. . . Bending radius (m).

dimension steel pipe da [mm]	R [m]	6 m α [°]	12 m α [°]
26,9	8,4	41	--
33,7	12,8	27	--
42,4	13,4	26	52
48,3	15,4	22	44
60,3	17,2	20	40
76,1	19,6	18	36
88,9	20,2	17	34
114,3	20,9	--	33
139,7	25,7	--	27
168,3	31,0	--	22
219,1	36,1	--	19

Table 2-4: Permitted bending radius and bending angle for bend-pipes, according to Isoplus

If the minimal bend-pipe radius for a DN 300 pipeline is determined according to the formula (1), the following value comes up:

$$R = \frac{5{,}599.8\ \text{mm}^2 \cdot 150\ \text{N/mm}^2}{0.04\ \text{N/mm}^2 \cdot 450\ \text{mm}^2} = 46.7\ \text{m}$$

Compared to the example with R = 20 m this is a fundamentally greater value. This lay out of the bend-pipe is retraceable to the low permitted strain of 150 N/mm² and the not later fulfilable lay out of the bend-pipe according the permitted earth pressure. The lay out of bend-pipes in relation to the criterion of highest permissible earth pressure is discussed at the end of this section.

Pan-Isovit

Pan-Isovit states as criteria for the installation:

1) For dimensions > DN 250 and a cover of $h_0 < 0{,}7$ m the highest permitted earth pressure is considered

2) Otherwise the permitted compression in the PUR foam is the lay out criterion, in which Pan-Isovit suggests as permitted value 0.1 N/mm² since it is, as they say, a primary requirement.

Furthermore is mentioned the economic acceptability of the production effort.

The manufacturer information set of Pan-Isovit indicates the smallest permitted curve radii for 12 m straight pipes as presented in table 2-5. The table takes into account the required straight pipe ends for manufacturing reasons. As a rule they have a length of 2,5 to 3 times the outside dimension of the steel pipe.

Pan-Isovit calls as installation criterion for installing bend-pipes vertically, that the theoretically increasing resistance should be at least 1.5 times the resistance in a straight pipeline.

DN	R = system radius lay out radius in m	α = change of direction in °
100	30	22,9
125	32	21,5
150	36	19,1
200	41	16,8
225	44	15,6
250	46	15,0

DN	R = system radius lay out radius in m	α = change of direction in °
300	52	13,2
350	58	11,9
400	62	11,1
450	68	10,1
500	73	9,4
600	84	8,2

Table 2-5: Smallest permitted bend-pipe radius for 12 m straight pipes according to details of Pan-Isovit.

Assessment of the results of the questionnaire

The answers on the laying out of bend-pipes indicate clearly that the manufacturers consulted have very different criteria for constructing the smallest bend-pipes radii. This shows how important the regulating efforts in process are for the installation of pre-insulated bonded pipes and therefore also a unitary laying out of bend-pipes in the context of the JWG1 in the TC 107 is necessary.

There are manufacturers which mention bend-pipes radius in sizes comparable to the example of calculation. TARCO and ABB belong to them. Other manufacturers indicate a clearly higher permitted radii for bend-pipes. Powerpipe, Isoplus and Pan-Isovit belong to this group. Particularly the criterion for installation "highest allowable earth pressure", stated by several manufacturers, is not in line with our understanding of bend-pipe mechanics.

Due to warming up there is lateral displacement which causes axial pressure of the soil on the pipe. The axial pressure causes compression in the PUR foam to reach a maximum value at the outside of the steel pipe. This axial pressure at radial moving was examined in [3] and is found to depend on the outside-dimension of the vertex casing, on the degree of solidification and on the earth forces.

Is the permitted radial PUR compression restricted to a maximum earth pressure of 0,15 N/mm² than a highest soil pressure of approx. 0,1 N/mm ² is not exceeded. The highest permitted earth pressure is not the lay out criterion for the bend-pipe in this case, because a soil pressure of approx. 0,1 N/mm ² is uncritical. The permitted compression in the PUR foam is the limiting value in every case. There are different opinions on the permitted value nowadays in which values up to 0,45 N/mm² are in discussion.

Risk of buckling at parallel excavation

Bend-pipes are compared to straight pipes almost not endangered concerning to buckling at parallel excavation. The bend-pipe is just more bent. It has a lateral displacement, which is for example for a DN 150-pipeline and a change of direction of 45° about 165 mm.

For the straight pipe the permissible length for parallel excavation is restricted. The permissible length depends on the dimension and the temperature difference between the laying temperature and the operation temperature. For a DN 150-pipeline the permissible length for parallel excavation is for pre-heated laying ($\Delta T = 60$ K) about 4 m.

Compensators

For the pre-insulated bonded pipes axial compensators were avoided if possible. They cause only higher costs and they have in addition a technical risk. If there is a pipeline with axial compensators that is combined with natural compensated sections, the pipe moves into the bend because of the inner pressure. This fact is valid for both, the bend-pipe and the straight pipe, because the bend-pipe behaves concerning to the axial stresses the same as the straight pipe.

3. Manufacture of bend-pipes

The bending of straight pipes to bend-pipes puts high requirements on the parts of the pre-insulated bonded pipe (steel service pipe, PUR foam and HDPE casing).

Metal is due to the malleable qualities of the material fit for bending, so the steel service pipe will be handled most simply when bend-pipes are manufactured. Point while bending the steel pipe is merely with what device the required deformation energy can be generated.

The HDPE casing material is, due to tough elasticity, limited in flexibility. An additional third material is the foam, which is connected stress free with the casing and the service pipe. These three very different materials are the reason why, when bending them together, each of all three components limits the attainable smallest bend-pipe radius for the production of bend-pipes.

The manufacturing methods of bend-pipes must be distinguished principally into the place of production in which there are two possibilities:

1. Production of the bend-pipes at the **construction site**
2. Production of the bend-pipes in the **factory**

At the **construction site** the complete straight pre-insulated bonded pipe is delivered on the spot and bend there.

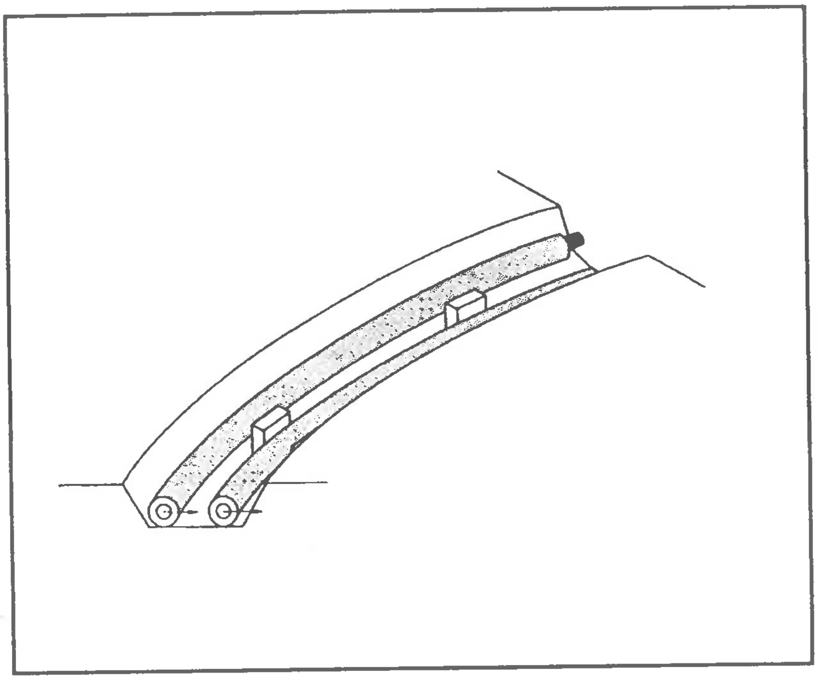
One can distinguish bending at the building site between

- elastic bending or pulling welded pipes and

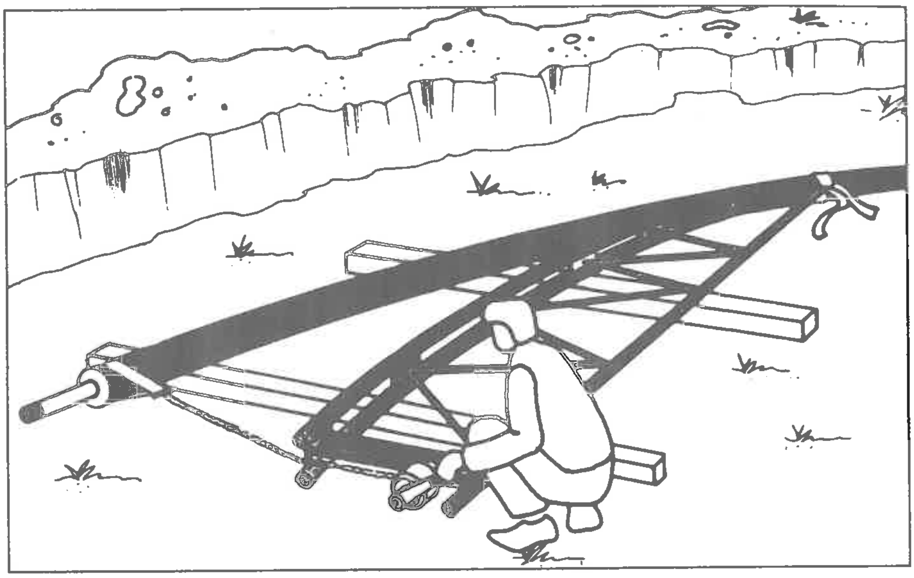
- bending with a bending tool.

Elastic bending is carried out in trenches with pipes welded together, as shown in picture 3-1. The smallest bending radius is limited by the moment of resistance of the pipe and the bending forces that can be developed in the pipe trench and which depend on the pipe dimension. Examples of the curve radius of elastic bending are mentioned in this section for the different manufacturers.

Every pipe is bent outside the pipe trench to the desired radius when bending with a bending tool. A bending tool can look like the one in picture 3-2 where a 3 m pipe DN 80 is bent. The bending tool must be used repeatedly for bending greater lengths. The bending radius is thus limited by the bending tool.



Picture 3-1 Elastic bends in the pipe trench [5]



Picture 3-2: Bending tool for bending on the construction site [6]

There are in principle two production methods for manufacturing bend-pipes in the factory:

- bending casing, foam and steel pipe **together** at once
- bending of service pipe and casing **separately** and foaming them afterward

The combined bending of service pipe and casing is commonly used for most manufacturers at smaller dimensions. It is no doubt the fastest and less expensive method, but it also contains risks. The PUR foam is particularly stressed when bending with strong loads with the danger of cracks in the foam, which cannot be recognised from the outside.

At larger dimensions separate bending is used. It is costlier but the bending is more controlled this way. Bending the HDPE casing is only restrictedly possible so that the casing of the bend-pipe must be produced from welded curve segments with a small bending radius.

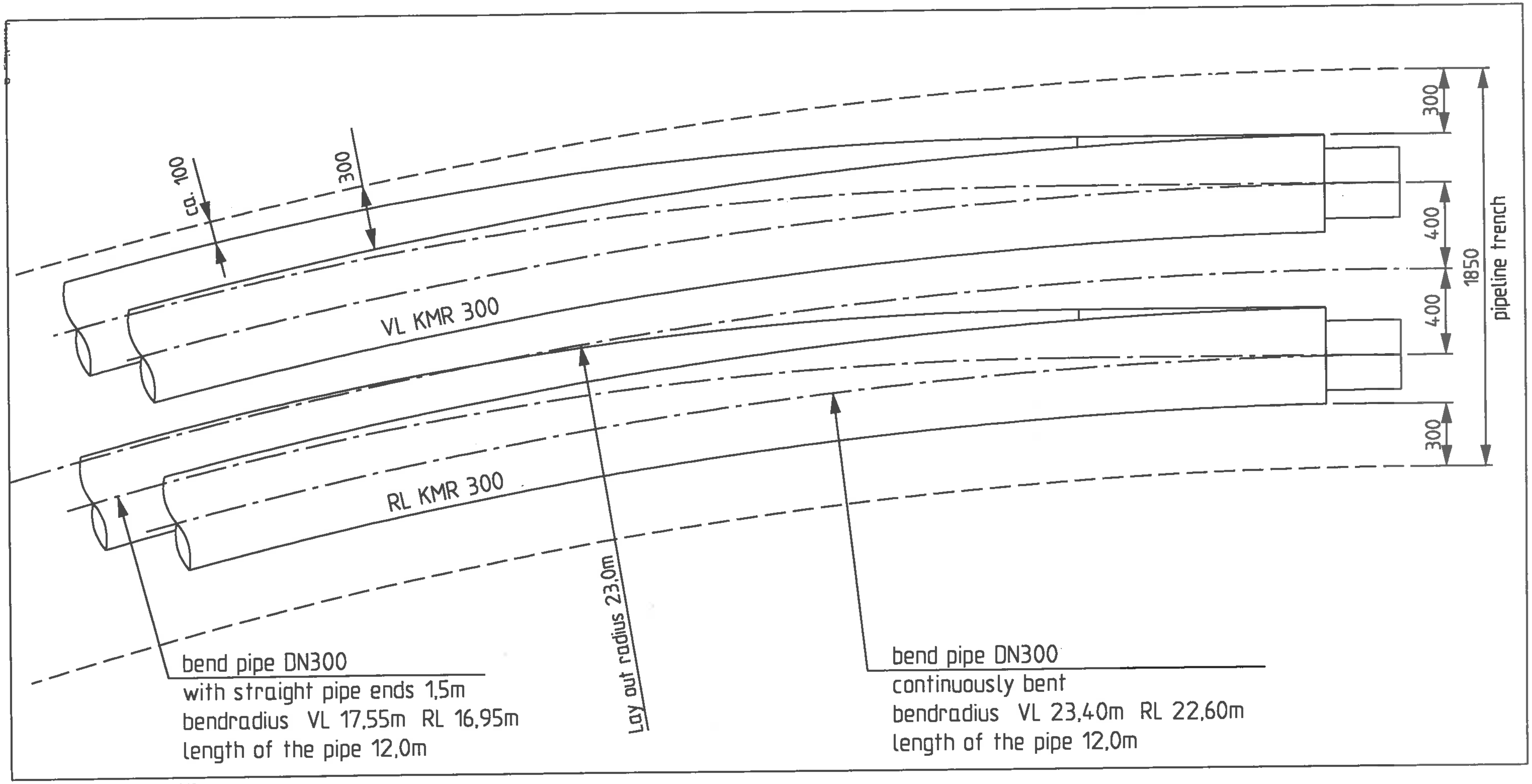
For both manufacturing methods straight ends of pipe are required for the power transfer. These are between 1.5 and 2.5 m at every end of the pipe depending on the dimension. The usable curve length is reduced considerably by this. For the real direction changes the installation radius is larger.

Continuously bent bend-pipes are desirable from the point of view of the planning engineer. Bend-pipes with straight ends of pipe must have a smaller bending radius in the actually bent area to be able to create the same projected installation radius. This has following disadvantages, which are obvious in the example of picture 3-3:

- The smaller bending radius may cause an undesirable approach of the outside pipe to the wall of the pipe trench. In picture 3-3 the movement is ca. 20 cm. The pipeline trench needs to be broader in the bend-pipe area or has to be reworked in the critical area.
- Not allowable high strains can appear in the bend-pipe by the smaller bending radius. Like in the example picture 3-3 the bending radius of the inner pipe of originally R = 22,6 m is reduced to R = 16,95 m. The permitted compression in the PUR foam be exceeded. Therefore the supplier of the bend-pipe should make sure with respect to straight ends of pipe on delivery of bend-pipes that no exceeding of the permitted static load appears.

See picture 3-3 on the next page.

The manufacturers were asked in the context of the questionnaire also on matters of manufacturing bend-pipes. The answers for every manufacturer are presented in the following.



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Picture 3-3: Bend-pipes with straight ends and the consequences on the pipeline trench

TARCO

TARCO states that up to DN 80 it is possible to bend the straight bonded pipes on the construction site with a bending tool. Up to DN 200 TARCO the bend-pipes are made from complete bonded pipes. Limiting criterion for the bending radius is the capacity for compression of the PUR foam is stretched. This manufacturing method results in straight pipe-ends of 2.5 m.

From DN 250 on service pipe and casing are bent separately at TARCO followed by foaming. The minimal bend-pipe radius is limited by the bending radius of the casing. At a smaller radii than approx. 40 m the bend casings are manufactured by welding curve segments together. According to TARCO elastic bending the pipe is limited by lateral instability. Smallest bending radii for elastic bending are mentioned in table 3-1.

DN	R [m]	centre line distance per 12 m [mm]	Angle per 12 m [°]
32	22	800	31
40	25	710	27
50	32	570	22
65	40	450	17
80	47	390	15
100	60	300	11
125	73	250	9
150	88	200	8
200	115	160	6
250	143	130	5
300	170	110	4
350	187	100	3
400	213	80	3

Table 3-1: Minimal bending radius of elastic bends according to TARCO

ABB-I.C. Moller

Bending with a bending tool is possible up to a DN 80 on the construction site according to ABB. Larger bend-pipe dimensions, up to DN 600 are produced at the factory by bending service and casing in one action. The minimal bending radius is not set by production but by the maximum permitted earth pressure of installation.

ABB-I.C. Moller has constructed a computer controlled bending machine, this bends automatically the pre-insulated pipes for the desired angle[7].

Basically bend-pipes can be produced through elastic bending up to an in table 3-2 mentioned minimal smallest radius with:

outside dimension steel pipe [mm]	smallest radius elastic bending	
	$V°_e$ (°)	R_e (m)
26,9	45	15
33,7	38	18
42,4	30	23
48,3	28	26
60,3	20	33
76,1	16	41
88,9	14	48
114,3	11	62
139,7	9	75
168,3	7	91
219,1	5,8	118
273,0	4,6	147
323,9	3,9	175
355,6	3,5	192
406,4	3,1	219
457,2	2,7	247
508,0	2,5	274
558,8	2,3	302
609,6	2,0	329

$V°_e$: maximum elastic angle per 12 m pipe
R_e: minimum elastic bending radius

Table 3-2: Smallest bending radius of elastic bending according to ABB

Powerpipe

For Powerpipe bending a straight pipe is possible on the construction site up to DN 80 with a bending tool. Powerpipe manufactures bend-pipes by bending complete pipes.

The minimal bending radius is, according to Powerpipe, limited by the bending radius of the casing for little dimensions, and for large dimensions by the lateral instability of the service pipeline.

Isoplus

Bending is possible up to DN 80 on the construction site according to Isoplus with bending tools. Isoplus manufactures bend-pipes by bending service pipe and casing together. The bending radius is set by the capacity for compression of the PUR hard foam and by lateral displacement of the service pipeline.

Elastic bending of straight pipes is, according to Isoplus, possible up to DN 500 , in which the in table 3-3 mentioned smallest bending radii are permitted.

pipe lenght l_x	d_a [mm]	R_{min} [m]	α_{zul} [°]
6 m	26,9	18	19
	33,7	22	15
	42,4	25	13
	48,3	35	10
	60,3	35	10
	76,1	42	8
	88,9	50	7
12 m	114,3	69	10
	139,7	78	8
	168,3	102	6
	219,1	128	5
	273,0	158	4,5
	323,9	189	3,5
	355,6	207	3,0
	406,4	229	2,8
	457,2	256	2,6
	508,0	292	2,4

Table 3-3: Smallest permitted elastic bending radius according to Isoplus

Pan-Isovit

No special bending tool is offered by Pan-Isovit for the construction site, so bending at the construction site is only possible through elastic bending.

At the factory Pan-Isovit manufactures bend-pipes by separately bending the casing and the service pipe. The smallest bending radius is limited by the bending radius of the casing.

4. Economy of using bend-pipes

The technical benefits of the use of bend-pipes is undisputed, however the cost factor must certainly be considered too.

The bend-pipe-producers were asked therefore after the costs of production of bend-pipes at their mills. The costs should be indicated in percentages. The value of the straight bonded pipe is set at 100 %. Table 4-1 shows the costs mentioned in response to the questionnaire.

Manufacturer	Costs for bend-pipes in % (100% straight covered pipe)		
TARCO	< DN 300 130 %	> DN 250 150-200 %	
ABB - I.C. Møller	115 - 125 %		
Powerpipe	130 %		
Isoplus	< DN 250 130 %	DN 250-300 140 %	> DN 300 145 %
Pan-Isovit	no information		

Table 4-1: Costs for bend-pipes bent at the factory indicated in percentage (100 % is the value of the straight bended pipe)

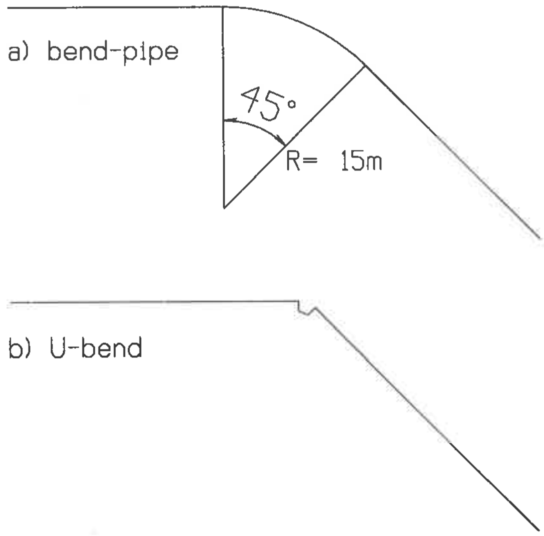
The change in cost for one dimension to the next at TARCO is e.g. manufacturer conditioned. At larger dimension the production is realised with separately bending cover and service pipeline and followed by foaming. A bend-pipe manufactured by many sequential process steps is more expensive than a bend-pipe bent in one single process step.

Higher specific costs of the bend-pipe must be compensated by more freedom of installation and simpler installation to be able to obtain an economic advantage. The economic advantages of the application of bend-pipes will be illustrated at two examples.

The cost for one 45 ° change of direction is compared in the first example. Picture 4-1 shows the situation at installation for the example.

Case 1: a 45 ° change of direction is created with a bend-pipe.

Case 2: an U-bend is installed as compensation element in the second case. A 45 ° bend is mechanically impossibly due to large movings.



Picture 4-1: Comparison of the realisation of a 45 ° change of direction with
a) a bend-pipe and
b) an U-bend

In table 4-1 the comparative costs for both cases are presented for a DN 100 distribution pipeline, in which a radius R = 15 m for the bend-pipe is pre-supposed.

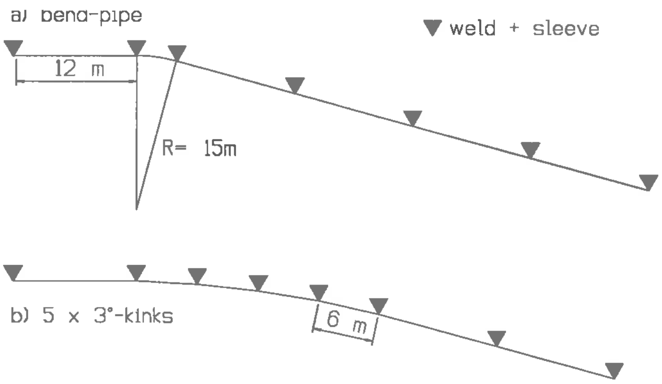
The following cost approaches got refined:

- straight pipe DN 100
  - material 60,- DM/m
  - assembly 30,- DM/m
- bend-pipe DN 100 (30 % higher cost of material)
  - material 78,- DM/m
  - assembly 30,- DM/m
- Additional costs for an U bend according to [8] 8,000,- DM/piece

	bend-pipe	U-bend
length of bend-pipe in m for R = 15 m	12	-
Costs of bend-pipe (S+R) material (DM) assembly (DM) U-bend (DM)	 1.872,- 720,- -	- 8.000,-
Total	2.592,- DM	8.000,- DM
Difference in costs (DM)	0,- DM	5.408,- DM

Table 4-1: Comparison of costs of the use of bend-pipes at the example of a 45 ° change of direction with a DN 100.

Second example is a comparison of costs of a 15 ° change of direction. A bend-pipe is the alternative to 5 x 3 ° kinks. In table 4-2 the comparative cost for both cases is represented, in which the 3 ° kinks are assumed to be realised with 6 m distance in between the kinks, as shown in picture 4-2.



picture 4-2: Comparison of the realisation of a 15 ° change of direction
a) with bend-pipe b) with 5 x 3 ° kinks

The following cost approaches got refined:

- costs for one weld 85,- DM/piece
- costs for a sleeves connection 200,- DM/piece

	Bend-pipe	5 x 3°-bends
length of the bend-pipe in m for R = 15 m	6	-
Bend-pipe costs (S+R)		
material (DM)	96,-	-
assembly (DM)	-	
number of additional welding	-	2
cost per welding (DM)		85,-
costs for welding (DM)	-	170,-
number of additional sleeves	-	2
costs per sleeve (DM)		400,-
costs for sleeves (DM)	-	-
Total	96,- DM	570,- DM
Costs difference	0,- DM	474,- DM

Table 4-2: Cost reduction by use of bend-pipes at the example of a 15 ° change of direction DN 100.

The pipe length is supposedly the same in both cases. The bend-pipe had to yield a shorter trace actually. Therefore extra material costs of 16,- DM/m are counted for the cost of the bend-pipe in table 4-7.

The installing is assumed with 12 m long pipes. Only in the area of the change of direction 6 m long parts were used, so the radius of the installation is as small as possible.

Both examples point out that by use of bend-pipes at changes of direction of 15° and 45° there is a potential for cost saving in between of 470 DM and 5.400 DM per change of direction.

The use of bend-pipes is particularly economical if changes of direction between 15° and 70° are to be created and if installation external requirements specially demand bend-pipes, like a street bend.

5. Application of bend-pipes for large dimensions at the example of a DN 800 transport pipeline.

A 15 km long transport pipeline a dimension of DN 800 has been projected for the district heating supply connection of a large energy plant in Germany. A variety of bend-pipes have been planned due to the advantages of the bend-pipes with regard to mechanics and economy.

16 bend-pipe elements were projected altogether with curve angles in between 7° and 32°. The trace for the installation got so elaborated that an uniform bend-pipe radius is set to R = 100 m. This uniformity is of advantage for an efficient production of bend-pipes.

In a questionnaire to potential manufacturers of bend-pipes before the planning was started they all agreed upon the possibility to produce DN 800 bend-pipes with a radius of R = 100 m. Bending 16 m long pipes however is only possible with straight ends. That reduces the effective bending length to approx. 10 m. At bend-pipes of the dimension DN 800 separate bending of cover and service pipeline is applied by all manufacturers as method of production.

After allocating the job for the pipelines it showed that the chosen manufacturer however had problems with the production of these bend-pipes anyway. His solution presented for solving the technical problem at the moment suggested the manufacturing of the bend-pipes by welding 6 m long straight steel service pipes with 3° kinks and then thrust over the bent PE casing. In comparison with the realisation with 3° kinks this has advantages while welding sleeves at the construction site creates weak spots in the system. Mechanically however it is around kinks where the load is higher than in continuously bend pipelines. Thereupon leads thrusting the bent PE cover over the 6 m long straight pipe ends to getting the service pipes close to the cover which leads to higher heat losses in the vicinity of the 3° bends and higher temperatures of the pipe wall will have to be considered.

Altogether such a technical solution must be rejected while 3° kinks are the subject and not bend-pipes. At the outside only these pipes are identical to bend-pipes. A definite technical solution has not yet been found.

6. Summary

Bend-pipes are virtually ideal installation elements since they are mechanically more trustworthy than straight pipes and offer high freedom of installation by allowing many curve angles.

There is not any norm internationally for bend-pipes in which the smallest permitted bend-pipe radius is stated. Therefore many different smallest admittable bend-pipe radii are stated by different manufacturers. These smallest radii are partially manufacturer conditioned, partially due to different installation processes of bend-pipes. Due to planning clearly smaller bend-pipe radii often are possible than those offered by the manufacturers. In the planner's vision this is very un-satisfying.

Therefore all leading European manufacturers of pre-installated bonded pipes were addressed for the questionnaire in the context of this essay on lay out, production and cost of bend-pipes. Five manufacturers from Denmark, Austria, Sweden and Germany have answered this questionnaire.

Answers concerning laying out of bend-pipes confirmed preliminary expectations for large differences with regard to criteria for lay out and the bend-pipe radii resulting. The example enclosed in the questionnaire of a bend-pipe DN 300 with a radius of 20 m shows these differences clearly. The smallest bending radius for such an installation the manufacturers needed up to 50 m. The indicated criteria for the installation differ greatly, now the "highest allowable earth pressure" was mentioned, than the "highest allowable compression in the PUR foam". A unity of criteria for installation seems to be needed urgently to remove the predominant uncertenties.

Clearly smaller differences manufacturers show at the manufacturing of bend-pipes. It is the same at practical all manufacturers:

- Up to the dimension DN 80 bend-pipes are produced on the construction site with the help of transportable bending tools.
- For larger dimensions (> DN 100) bend-pipes are manufactured at the factory, in which in principle up to a dimension of approx. DN 200 the complete pipe is bent.
- For dimensions larger than DN 250 as well complete as separate bending is practised. Bending the complete pipe is limited by the compression of the PUR foam and by the lateral displacement of the PE casing. When bending separately the smallest bending radius is determined by the bending force of the casing. Therefore at small bending radii the PE casing is created by some manufacturers by welding segments.
- At all dimensions elastic bending in the pipe trench on the construction site is possible for several pipes which are welded together.

Costs for bend-pipes manufactured at the factory were indicated by manufacturers as additional costs percentages in relation to straight bonded pipes. The price margin of the manufacturers goes up to 200 % from 115 % in which 100 % apply to the straight pipe.

Single manufacturers have mentioned price details depending on the dimensions of the pipes. On the average one can use the following additional costs for bend-pipes:

< DN 300	120 -- 130 %
DN 300 - 600	140 -- 160 %
> DN 600	160 -- 200 %

The economy of use of bend-pipes with assumed changes of direction at two examples of 45 ° and 15 ° are not rejected.

In conclusion a current project experience was described to reveal problems that may appear at using bend-pipes at a DN 800 transport pipeline.

7. Acknowledgements

[1] FN Dinslaken: Forschungsbericht "Betriebliche Selbstvorspannung"- Unterverteilung -, noch unveröffentlicht (1995)

[2] Rumpel, W.: Unveröffentlichte Auszüge aus der Überarbeitung der KMR-Richtlinie im Auftrag der AGFW, Berlin (1995)

[3] Audibert, J.M.E. und Nynman, K.J.: Soil Restraint against horizontal Motion of Pipes Journal of the Geotechnical Engineering Division, Oct. (1977)

[4] GEFKMR: Statikprogramm für Kunststoffverbundmantelrohre

[5] Herstellerkatalog TARCO

[6] Handbuch ABB-I.C. Moller

[7] Jacobsen, G.: Bogenrohr: Ein Kolumbus-Ei, das die Fernwärme-Verbundrohrsysteme der Zukunft verbessert und verbilligt FWI-Fernwärme International, Jg. 17, 4 (1988)

[8] Gerke-Reineke, L.: Wie erreicht man Kostenuntergrenzen mit dem KunststoffMantelrohr? FWI-Fernwärme International, Jg. 15, 4 (1986)

Appendix

Appendix A:

Questionnaire on lay out, production and economy of bend-pipes.

Appendix B

Calculations for tension and substance with the GEFKMR program for a 45 ° change of direction, DN 300.

Appendix A

Following manufacturers answered the questionnaire:

1. ABB District Heating Technology
   Treldevej 191
   DK - 7000 Fredericia
   Compiler: H. Nørgaard Pedersen

2. TARCO ENERGI A/S
   Erritso Møllebanke 10
   DK - 7000 Fredericia
   Compiler: Bjarne Jepsen

3. Powerpipe AB
   Ellesbovägen 101
   S - 42505 Hisings-Kärra
   Compiler: Göran Johansson

4. Isoplus Fernwärmetechnik Gesellschaft mbH
   Furthoferstraße 1a
   A - 3192 Hohenberg
   Compiler: Hr. Wagner / Stritzel

5. Pan-Isovit GmbH
   Siemensstraße 18
   D - 67346 Speyer
   Compiler: Hr. Gramm

Questionnaire <u>Please return by 15th October 1994</u>

Bend-pipes for pre-insulated bonded pipe-systems

Compiler: ....

Tel. Extension: ....

Company (Stamp): ....

Address: ....

Section A: Design of bend-pipes

1. Which criteria determine the design of horizontally laid bend-pipes in your opinion?

☐ maximum permissible earth pressure

☐ permissible stress in the HDPE pre-insulated pipe

☐ permissible pressure stress in the PUR foam

☐ permissible circumferential stress in the steel pipe

2. Do you have basic material (publications, test results) which you would like to make available for this study?

☐ Yes, as follows: ....
....
....
....
....
....

☐ No

3. Do you have practical experience in the application of especially narrow line-radii with great nominal widths?

	DN	R [m]	Operator
☐ Yes, as follows	....	....	....
	....	....	....
	....	....	....
	....	....	....

☐ No

4. How do you determine the permissible radius for the vertical laying of bend-pipes?

Section B: Manufacture (bending) of bend-pipes

5. Up to which nominal width can your pre-insulated pipes be bent on site without using bending equipment?

☐ up to DN ....

☐ not at all

6. Up to which nominal width can your pre-insulated pipes be bent on site with bending equipment?

☐ up to DN ....

☐ not at all

7. How do you bend bend-pipes with great nomonal width in the works?

☐ not at all

☐ Medium-pipe and jacket-pipe are bent separately and then foamed.

☐ Fininshed (straight) pre-insulated pipes are bent in a special production facility.

8. How are the minimum bending radii of your bend-pipes limited in works production?

☐ by the bend-radius of the jacket pipes (tighter bends are only possible as segment bends)

☐ by the bending radius of the medium pipe

☐ Other reasons
....
....
....
....

☐ by the stretch absorbtion of the PUR hard foam

☐ by fold formation in the medium pipe

☐ Other reasons
....
....
....
....

Section C: Economy of bend-pipes

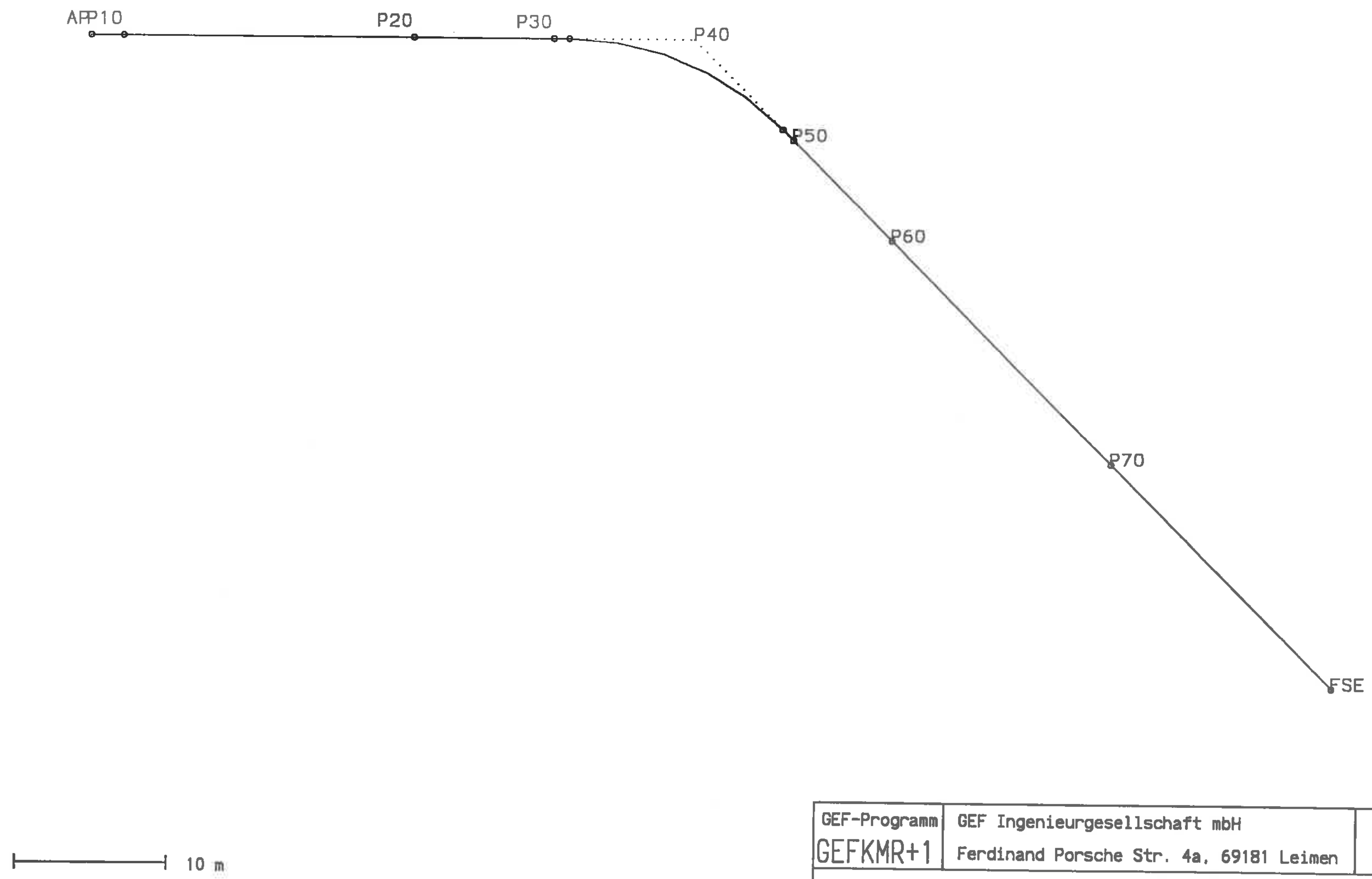
9. If the cost of a straight pre-insulated pipe is 100 %, how high are then the costs of a bend-pipe of the same length manufactured in the works?

......................%

10. Please furnish us with detailed illustrative material (special brochures) concerning

- site bending-equipment
- works bending-machinery and
- bend-pipe laying

Appendix B



GEF-Programm GEFKMR+1	GEF Ingenieurgesellschaft mbH Ferdinand Porsche Str. 4a, 69181 Leimen	15.01.96 80161
Auftraggeber:	IEA District Heating and Cooling	
Rechenfall:	Minimum route radius	

G E F Ingenieurgesellschaft mbH

Minimum route radius

G E F K M R , Version 8.0 (94.1)

Static calculation of Curved pipes
considering nonlinear bedding functions
* FR'(v) - Raising the axial frictional force FRg' and
* Q'(v) - additional lateral longitudinal force
with v - lateral projection

C A L C U L A T I O N B A S I S

- Reducing process with more intensive separation of the static unknowns (to guarantee numerical stability)
- Constant-force process for the iterative determination of the friction

---

I N P U T D A T A

Commission -No.: 80161
Customer : IEA District Heating and Cooling

Prestressing temperature	10.00	degr.C	
Laying temperature	10.00	degr.C	
Temperature(max)	120.00	degr.C	
Outside diameter	323.90	mm	
Wall thickness	5.60	mm	
Diameter of jacket pipe	450.00	mm	
E-Modulus	205.00	kN/mm2	
Coefficient of expansion	1.12	E-05 1/K	
Allow. PUR compressive stress .	0.15	N/mm2	
Int. overpressure	16.00	bar	
Coverage	1.00	m	
Angle of the int. friction	32.50	degr	
Gamma	19.00	kN/m3	
Length of long leg	40.00	m	
Length of short leg	60.00	m	
Route radius	20.00	m	
Angle of deviation	45.00	degr	
Bedding type, ground	2	-	medium compaction
Reducing factor, friction force	0.85	0.85 1.00 -	
Supplement for road surface ...	0.50	m	

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

Extract of results (max. values)

1. Variation zone(s) (m)	Condition warm	cold
Total variation length	97.4	64.6

2. Displacements (mm)	warm	cold
Displacement axial, at end of system .	77.6	32.3
Displacement lateral, in bend	-1.4	1.0

3. PUR-foam and jacket pipe	warm	allow.	cold
PUR-shear tension (MPa)	0.023	0.030	0.018
PUR-pressure tension (MPa)	0.126	0.150	0.092

4. Steel pipe
4.1. Surroun. tension caused by int. press. and annul. bend. stress(MPa)

P = 0.00 bar:	warm	allow.	cold	allow.
Annul. bending stress by lat. pressure	62.3	138.1	45.6	156.7

P = 16.00 bar:	warm	allow.	cold	allow.
Surroun. tension from int. pressure...	45.6		45.6	
Annul. bending stress by lat. pressure	35.6		45.6	
Surrounding tension (total)	81.2	138.1	91.3	156.7

4.2. Detailed stress analysis
at the location with the max. reference stress

Stress determination and assessment based on ASME und AD-S2

Type of tension (MPa)	Superposition: warm - cold
Nom. tension caused by int. pressure .	45.63
Tangential tension	67.50
Axial tension	-243.68
Radial tension	0.00
Annular bending tension	21.87
Total tension	311.18

Allowable value 909.00

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

S U B D I V I S I O N O F S E C T I O N

Length	2.14	m	Section: 1	
Spacing	1	-	AP	- P10
Length	19.29	m	Section: 2	
Spacing	9	-	P10	- P20
Length	9.28	m	Section: 3	
Spacing	10	-	P20	- P30
Length	9.28	m	Section: 4	
Spacing	10	-	P30	- P40
Angular deviation	45.00	degr		
Length	9.28	m	Section: 5	
Spacing	10	-	P40	- P50
Length	9.28	m	Section: 6	
Spacing	10	-	P50	- P60
Length	20.72	m	Section: 7	
Spacing	10	-	P60	- P70
Length	20.72	m	Section: 8	
Spacing	10	-	P70	- FSE

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

R E S U L T S Load combination 1: Hot condition (adt=adt_warm)

Internal forces

u - Displacement axial, positive: in calculation direction in mm
v - Displacement lateral, positive: horizontal to right in mm
psi - Turning about the vertical axis, positive: right turning in mrad
M - Bending moment in kNm at pos. section edge, pos. direction like psi
N - Axial force in kN ditto , pos. = tensile load
Q - Lateral force in kN ditto
SIGV - Reference stress in MPa (Maximum from calculation on inner- and outer fibre with 10 degr. steps in circum. direction, local stress factors based on ASME)
Stress-range from the action ranges of the superposition condition warm*(+1) + condition cold*(-1)

More results and estimations

FRg' - Axial frictional force - total in kN/m
Q' (v) - Additional lateral line load caused by v-displ. in kN/m
SNR - Section number within a section
KZ = G - Characteristic for the straight area
KZ = B - Characteristic for bends

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
						Section: 1, from: AP to: P10				
0	G	0.0	0.0	0.0	0.0	0.0	0.00	-1002.73	0.00	303.5
1	G	6.2	0.0	0.6	0.0	0.0	-0.00	-996.09	0.00	302.6
						Section: 2, from: P10 to: P20				
0	G	6.2	0.0	0.6	0.0	0.0	-0.00	-996.09	0.00	302.6
1	G	9.8	0.0	1.3	0.0	-0.0	-0.00	-978.93	0.00	300.4
2	G	9.8	0.0	2.0	0.0	0.0	0.00	-957.90	-0.00	297.9
3	G	9.8	0.0	2.7	0.0	-0.0	-0.00	-936.86	0.00	295.8
4	G	9.8	0.0	3.5	0.0	0.0	0.00	-915.82	-0.00	294.0
5	G	9.8	0.0	4.3	0.0	-0.0	-0.00	-894.77	0.00	292.3
6	G	9.8	0.0	5.1	0.0	0.0	0.00	-873.71	-0.00	290.8
7	G	9.8	0.0	6.0	0.0	-0.0	-0.00	-852.64	0.00	289.3
8	G	9.8	0.0	7.0	0.0	0.0	0.00	-831.57	-0.00	287.8
9	G	9.8	0.0	7.9	0.0	-0.0	-0.00	-810.50	0.00	286.3
						Section: 3, from: P20 to: P30				
0	G	9.8	0.0	7.9	0.0	-0.0	-0.00	-810.50	0.00	286.3
1	G	9.8	0.0	8.4	-0.0	-0.0	-0.00	-801.37	0.00	285.6
2	G	9.8	0.0	8.8	-0.0	0.0	0.00	-792.23	-0.00	284.8
3	G	9.8	0.0	9.2	-0.0	-0.0	-0.00	-783.10	0.00	284.1
4	G	9.8	0.0	9.7	0.0	0.0	0.00	-773.96	-0.01	283.3
5	G	9.8	0.0	10.2	0.0	-0.0	-0.02	-764.83	0.02	282.4
6	G	9.8	0.0	10.6	0.0	0.0	0.07	-755.69	-0.09	281.7
7	G	9.8	0.0	11.1	0.0	-0.0	-0.24	-746.55	0.33	281.3
8	G	9.8	0.0	11.6	0.0	0.0	0.91	-737.42	-1.24	282.6

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
9	G	9.8	0.0	12.1	-0.0	-0.1	-3.39	-728.28	4.63	290.4
10	G	10.1	5.3	12.6	-0.2	-0.3	-2.79	-719.01	-3.12	299.2

Section: 4, from: P30 to: P40

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
0	G	10.1	5.3	12.6	-0.2	-0.3	-2.79	-719.01	-3.12	299.2
1	G	10.2	6.2	12.6	-0.2	-0.3	-2.46	-717.99	-3.69	299.5
2	G	10.4	7.2	12.7	-0.2	-0.3	-2.06	-716.96	-4.37	299.8
3	G	10.5	8.2	12.7	-0.2	-0.3	-1.58	-715.92	-5.13	299.9
4	G	10.7	9.2	12.8	-0.3	-0.3	-1.03	-714.86	-6.00	299.8
5	G	10.9	10.3	12.8	-0.3	-0.3	-0.38	-713.78	-6.98	299.5
6	G	11.1	11.3	12.9	-0.3	-0.3	0.37	-712.68	-8.05	298.9
7	G	11.4	12.3	12.9	-0.4	-0.3	1.23	-711.55	-9.23	298.0
8	G	11.7	13.3	13.0	-0.4	-0.3	2.21	-710.40	-10.51	296.6
9	G	11.9	14.2	13.1	-0.4	-0.3	3.33	-709.22	-11.89	297.5
10	G	12.2	15.0	13.1	-0.5	-0.3	4.59	-708.02	-13.35	304.8
0	B	12.2	15.0	13.1	-0.5	-0.3	4.59	-708.02	-13.35	304.8
3	B	23.3	39.3	13.9	-1.3	0.5	5.76	-677.82	3.79	305.9
6	B	23.5	40.0	14.7	-1.4	0.8	0.95	-640.38	1.72	292.7
9	B	22.4	36.7	15.6	-1.2	0.9	0.05	-604.25	0.04	287.4
12	B	21.7	34.5	16.6	-1.1	0.9	0.32	-569.62	-0.08	284.3
15	B	21.2	32.9	17.5	-1.1	0.9	0.46	-535.96	0.05	280.1
15	B	21.2	32.9	17.5	-1.1	0.9	0.46	-535.96	0.05	280.1
18	B	20.7	31.3	18.6	-1.0	1.0	0.46	-503.12	0.06	273.9
21	B	19.9	29.9	19.7	-1.0	1.0	0.59	-471.15	-0.13	266.4
24	B	18.5	27.9	20.8	-0.9	1.1	1.08	-440.89	-0.22	262.2
27	B	15.9	23.7	22.0	-0.7	1.2	0.41	-413.68	2.10	260.6
30	B	15.8	23.5	23.2	-0.7	0.9	-7.63	-389.27	8.00	231.3

Section: 5, from: P40 to: P50

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
0	G	15.8	23.5	23.2	-0.7	0.9	-7.63	-389.27	8.00	231.3
1	G	14.5	21.0	23.3	-0.6	0.9	-8.31	-387.75	5.78	230.2
2	G	13.5	18.5	23.4	-0.6	0.8	-8.78	-386.36	3.80	228.9
3	G	12.6	16.2	23.5	-0.5	0.7	-9.07	-385.05	2.07	227.5
4	G	11.9	14.0	23.5	-0.4	0.7	-9.19	-383.83	0.56	226.1
5	G	11.3	12.0	23.6	-0.4	0.6	-9.18	-382.67	-0.74	224.7
6	G	10.9	10.1	23.7	-0.3	0.5	-9.05	-381.56	-1.85	223.2
7	G	10.6	8.5	23.8	-0.2	0.5	-8.81	-380.48	-2.78	221.8
8	G	10.3	6.9	23.9	-0.2	0.4	-8.49	-379.44	-3.55	220.4
9	G	10.2	5.6	24.0	-0.2	0.4	-8.10	-378.41	-4.18	219.1
10	G	10.1	4.4	24.0	-0.1	0.3	-7.66	-377.40	-4.68	217.9

Section: 6, from: P50 to: P60

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
0	G	10.1	4.4	24.0	-0.1	0.3	-7.66	-377.40	-4.68	217.9
1	G	9.9	0.0	24.8	-0.0	0.0	-1.40	-368.16	-6.74	207.2
2	G	9.9	0.0	25.6	0.0	-0.0	0.37	-359.01	-1.91	197.7
3	G	9.9	0.0	26.4	0.0	0.0	-0.10	-349.86	0.51	192.8
4	G	9.9	0.0	27.2	0.0	-0.0	0.03	-340.71	-0.14	189.1
5	G	9.9	0.0	28.0	0.0	0.0	-0.01	-331.55	0.04	185.8
6	G	9.9	0.0	28.8	0.0	-0.0	0.00	-322.40	-0.01	182.5
7	G	9.9	0.0	29.7	0.0	0.0	-0.00	-313.25	0.00	179.2
8	G	9.9	0.0	30.5	0.0	-0.0	0.00	-304.09	-0.00	176.0
9	G	9.9	0.0	31.3	0.0	0.0	-0.00	-294.94	0.00	172.7
10	G	9.9	0.0	32.2	0.0	0.0	-0.00	-285.79	-0.00	169.4

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
						Section:	7,	from: P60	to: P70	
0	G	9.9	0.0	32.2	0.0	0.0	-0.00	-285.79	-0.00	169.4
1	G	9.9	0.0	34.1	-0.0	-0.0	0.00	-265.36	-0.00	162.2
2	G	9.9	0.0	36.1	-0.0	0.0	-0.00	-244.94	0.00	154.9
3	G	9.9	0.0	38.1	-0.0	-0.0	0.00	-224.51	-0.00	147.6
4	G	9.9	0.0	40.1	-0.0	0.0	-0.00	-204.08	0.00	140.3
5	G	9.9	0.0	42.2	-0.0	-0.0	0.00	-183.65	-0.00	133.1
6	G	9.9	0.0	44.3	-0.0	0.0	-0.00	-163.22	0.00	125.8
7	G	9.9	0.0	46.4	-0.0	-0.0	0.00	-142.79	-0.00	118.5
8	G	9.9	0.0	48.6	-0.0	0.0	-0.00	-122.36	0.00	111.2
9	G	9.9	0.0	50.8	-0.0	-0.0	0.00	-101.93	-0.00	103.9
10	G	9.9	0.0	53.0	-0.0	0.0	0.00	-81.49	0.00	96.6
						Section:	8,	from: P70	to: FSE	
0	G	9.9	0.0	53.0	-0.0	0.0	0.00	-81.49	0.00	96.6
1	G	9.9	0.0	55.3	-0.0	0.0	-0.00	-61.06	0.00	89.3
2	G	9.9	0.0	57.7	-0.0	-0.0	0.00	-40.62	-0.00	82.0
3	G	9.9	0.0	60.0	-0.0	0.0	-0.00	-20.19	0.00	74.8
4	G	9.9	0.0	62.4	-0.0	-0.0	0.00	0.25	-0.00	67.5
5	G	9.9	0.0	64.9	-0.0	0.0	-0.00	20.68	0.00	60.2
6	G	9.9	0.0	67.3	-0.0	-0.0	0.00	41.12	-0.00	52.9
7	G	9.9	0.0	69.8	-0.0	0.0	-0.00	61.56	0.00	47.2
8	G	9.9	0.0	72.4	-0.0	-0.0	0.00	82.00	-0.00	47.2
9	G	9.9	0.0	75.0	-0.0	0.0	-0.00	102.44	0.00	47.2
10	G	9.9	0.0	77.6	-0.0	-0.0	0.00	122.88	-0.00	47.2

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Minimum route radius

Extract of results (max. values)

1. PUR-foam and jacket pipe

ANR - Section number
TAUPUR - PUR-Shear tension in MPa
SIGPUR - PUR-Pressure tension in MPa
Other characteristics as before
tEC - thick.exp.cushion in mm

ANR	KZ	FRg'	TAUPUR	Q'(v)	SIGPUR exist.	SIGPUR all.	tEC
1	G	-6.2	-0.006	-0.0	0.0000	0.1500	0
2	G	-9.8	-0.010	-0.0	0.0000	0.1500	0
3	G	-10.1	-0.010	5.3	0.0164	0.1500	0
4	G	-12.2	-0.012	15.0	0.0465	0.1500	0
4	B	-23.8	-0.023	40.8	0.1260	0.1500	0
5	G	-15.8	-0.016	23.5	0.0725	0.1500	0
6	G	-10.1	-0.010	4.4	0.0137	0.1500	0
7	G	-9.9	-0.010	-0.0	0.0000	0.1500	0
8	G	-9.9	-0.010	0.0	0.0000	0.1500	0

Allow. values 0.030

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2. Steel pipe
2.1. Max. surrounding tension from inner pressure and annul.bending

PHI	- angle in segment in degr
P	- inner pressure in bar
SIGT(P)	- circum. tension caused by inner pressure in MPa
SIGT(Rb)	- circum. bending stress caused by lateral compression in MPa
SIGT	- SIGT(P) + SIGT(Rb)
all. SIGT	- allowable tangential stress in MPa

ANR	SNR	KZ	PHI	P	SIGT(P)	SIGT(Rb)	SIGT	all. SIGT
4	4	B	90	0.00	0.0	62.3	62.3	138.1
4	4	B	90	16.00	45.6	35.6	81.2	138.1

2.2. Detailed stress analysis
at the location with the max. reference stress

Stress determination and assessment based on ASME und AD-S2

The maximum reference stress occurs at

ANR	SNR	KZ	PHI	FIBRE
4	1	B	270	outer

Type of stress (in MPa)	i	SIG..
Nom. stress caused by int. pressure	1.0000	45.63
Tangential stress		67.50
Axial stress		-243.68
Radial stress		0.00
Circumferential bending stress	-0.0313	21.87
Total stress		311.18
allowable value		909.00

2.3. Axial stress caused by friction

The maximum axial stress amounts to 179.06 MPa und occurs in:

ANR	SNR
1	0

The allowable axial stress of 190.00 MPa is not crossed.

Minimum route radius

R E S U L T S Load combination 2: Cold condition (adt=adt_cold)

Internal forces

- u - Displacement axial, positive: in calculation direction in mm
- v - Displacement lateral, positive: horizontal to right in mm
- psi - Turning about the vertical axis, positive: right turning in mrad
- M - Bending moment in kNm at pos. section edge, pos. direction like psi
- N - Axial force in kN ditto , pos. = tensile load
- Q - Lateral force in kN ditto
- SIGV - Reference stress in MPa (Maximum from calculation on inner- and outer fibre with 10 degr. steps in circum. direction, local stress factors based on ASME) Stress-range from the action ranges of the superposition condition warm*(+1) + condition cold*(-1)

More results and estimations

- FRg' - Axial frictional force - total in kN/m
- Q' (v) - Additional lateral line load caused by v-displ. in kN/m
- SNR - Section number within a section
- KZ = G - Characteristic for the straight area
- KZ = B - Characteristic for bends

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
						Section:	1,	from: AP	to: P10	
0	G	0.0	0.0	0.0	0.0	0.0	-0.00	441.35	-0.00	303.5
1	G	1.5	0.0	0.8	-0.0	-0.0	0.00	442.98	-0.00	302.6
						Section:	2,	from: P10	to: P20	
0	G	1.5	0.0	0.8	-0.0	-0.0	0.00	442.98	-0.00	302.6
1	G	2.8	0.0	1.6	-0.0	0.0	0.00	447.66	-0.00	300.4
2	G	3.9	0.0	2.4	-0.0	-0.0	-0.00	454.88	0.00	297.9
3	G	4.7	0.0	3.2	-0.0	0.0	0.00	464.10	-0.00	295.8
4	G	5.3	0.0	4.0	-0.0	-0.0	-0.00	474.83	0.00	294.0
5	G	5.7	0.0	4.9	-0.0	0.0	0.00	486.62	-0.00	292.3
6	G	5.9	0.0	5.7	0.0	-0.0	-0.00	499.11	0.00	290.8
7	G	6.0	0.0	6.6	0.0	0.0	0.00	511.91	-0.00	289.3
8	G	5.9	0.0	7.6	0.0	-0.0	-0.00	524.69	0.00	287.8
9	G	5.7	0.0	8.5	-0.0	0.0	0.00	537.08	-0.00	286.3
						Section:	3,	from: P20	to: P30	
0	G	5.7	0.0	8.5	-0.0	0.0	0.00	537.08	-0.00	286.3
1	G	5.5	0.0	8.9	0.0	0.0	0.00	542.25	-0.00	285.6
2	G	5.3	0.0	9.3	-0.0	-0.0	-0.00	547.25	0.00	284.8
3	G	5.0	0.0	9.7	-0.0	0.0	0.00	552.04	-0.00	284.1
4	G	4.8	0.0	10.2	-0.0	-0.0	-0.00	556.59	0.00	283.3
5	G	4.5	0.0	10.6	-0.0	0.0	0.01	560.87	-0.01	282.4
6	G	4.1	0.0	11.0	-0.0	-0.0	-0.04	564.83	0.05	281.7
7	G	3.7	0.0	11.5	-0.0	0.0	0.14	568.45	-0.19	281.3
8	G	3.2	0.0	11.9	-0.0	-0.0	-0.51	571.67	0.70	282.6

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Minimum route radius

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
9	G	2.7	0.0	12.3	-0.0	0.0	1.91	574.45	-2.61	290.4
10	G	2.2	4.5	12.8	0.1	0.3	6.47	576.76	-2.84	299.2
Section: 4, from: P30 to: P40										
0	G	2.2	4.5	12.8	0.1	0.3	6.47	576.76	-2.84	299.2
1	G	2.2	5.5	12.8	0.2	0.3	6.73	576.98	-2.34	299.5
2	G	2.2	6.7	12.9	0.2	0.4	6.94	577.20	-1.72	299.8
3	G	2.1	8.1	12.9	0.2	0.4	7.08	577.41	-0.98	299.9
4	G	2.1	9.5	13.0	0.3	0.5	7.14	577.62	-0.10	299.8
5	G	2.1	11.1	13.0	0.3	0.5	7.10	577.83	0.93	299.5
6	G	2.1	12.9	13.1	0.4	0.6	6.95	578.05	2.13	298.9
7	G	2.1	14.7	13.1	0.4	0.6	6.67	578.26	3.51	298.0
8	G	2.1	16.6	13.2	0.5	0.6	6.25	578.47	5.08	296.6
9	G	2.2	18.7	13.2	0.6	0.7	5.66	578.69	6.84	297.5
10	G	2.2	20.8	13.3	0.6	0.7	4.88	578.91	8.81	304.8
0	B	2.2	20.8	13.3	0.6	0.7	4.88	578.91	8.81	304.8
3	B	2.9	26.9	14.1	0.9	0.8	-0.86	583.07	0.46	305.9
6	B	3.4	29.7	14.9	1.0	0.8	-0.13	588.06	-0.57	292.7
9	B	2.7	29.9	15.8	1.0	0.8	0.40	592.90	-0.11	287.4
12	B	0.9	29.8	16.6	1.0	0.8	0.41	595.84	0.05	284.3
15	B	1.8	29.7	17.4	1.0	0.9	0.35	595.30	0.01	280.1
15	B	1.8	29.7	17.4	1.0	0.9	0.35	595.30	0.01	280.1
18	B	5.4	29.4	18.3	0.9	0.9	0.39	589.76	-0.11	273.9
21	B	10.2	29.0	19.1	0.9	1.0	0.63	577.64	-0.17	266.4
24	B	16.5	29.5	19.9	0.9	1.0	0.23	556.95	1.08	262.2
27	B	17.4	27.6	20.7	0.9	0.9	-4.10	529.01	4.20	260.6
30	B	9.7	2.4	21.4	0.1	0.2	-7.22	507.80	-7.92	231.3
Section: 5, from: P40 to: P50										
0	G	9.7	2.4	21.4	0.1	0.2	-7.22	507.80	-7.92	231.3
1	G	9.7	2.9	21.5	0.1	0.1	-6.44	506.83	-7.66	230.2
2	G	9.7	3.3	21.5	0.1	0.1	-5.69	505.86	-7.35	228.9
3	G	9.8	3.5	21.6	0.1	0.0	-4.97	504.89	-7.01	227.5
4	G	9.8	3.6	21.6	0.1	0.0	-4.29	503.91	-6.66	226.1
5	G	9.8	3.6	21.6	0.1	-0.0	-3.64	502.93	-6.30	224.7
6	G	9.8	3.5	21.7	0.1	-0.0	-3.03	501.96	-5.95	223.2
7	G	9.8	3.3	21.7	0.1	-0.1	-2.45	500.98	-5.61	221.8
8	G	9.8	3.1	21.8	0.1	-0.1	-1.91	500.00	-5.29	220.4
9	G	9.7	2.9	21.8	0.1	-0.1	-1.40	499.03	-4.98	219.1
10	G	9.7	2.6	21.8	0.1	-0.1	-0.91	498.05	-4.71	217.9
Section: 6, from: P50 to: P60										
0	G	9.7	2.6	21.8	0.1	-0.1	-0.91	498.05	-4.71	217.9
1	G	9.7	0.0	22.2	-0.0	-0.0	2.34	489.03	-3.50	207.2
2	G	9.7	0.0	22.6	-0.0	0.0	-0.63	480.02	3.20	197.7
3	G	9.7	0.0	23.0	-0.0	-0.0	0.17	470.99	-0.86	192.8
4	G	9.7	0.0	23.3	-0.0	0.0	-0.05	461.95	0.23	189.1
5	G	9.8	0.0	23.7	-0.0	-0.0	0.01	452.90	-0.06	185.8
6	G	9.8	0.0	24.0	-0.0	0.0	-0.00	443.84	0.02	182.5
7	G	9.8	0.0	24.4	-0.0	-0.0	0.00	434.78	-0.00	179.2
8	G	9.8	0.0	24.7	-0.0	0.0	-0.00	425.70	0.00	176.0
9	G	9.8	0.0	25.0	-0.0	-0.0	0.00	416.62	-0.00	172.7
10	G	9.8	0.0	25.3	-0.0	-0.0	0.00	407.54	0.00	169.4

G E F I n g e n i e u r g e s e l l s c h a f t m b H

Minimum route radius

SNR	KZ	FRg'	Q'(v)	u	v	psi	M	N	Q	SIGV
						Section:	7,	from: P60	to: P70	
0	G	9.8	0.0	25.3	-0.0	-0.0	0.00	407.54	0.00	169.4
1	G	9.8	0.0	26.0	-0.0	0.0	-0.00	387.25	0.00	162.2
2	G	9.8	0.0	26.6	-0.0	-0.0	0.00	366.94	-0.00	154.9
3	G	9.8	0.0	27.3	-0.0	0.0	-0.00	346.61	0.00	147.6
4	G	9.8	0.0	27.8	-0.0	-0.0	0.00	326.28	-0.00	140.3
5	G	9.8	0.0	28.4	-0.0	0.0	-0.00	305.93	0.00	133.1
6	G	9.8	0.0	28.9	-0.0	-0.0	0.00	285.57	-0.00	125.8
7	G	9.8	0.0	29.4	-0.0	0.0	-0.00	265.20	0.00	118.5
8	G	9.8	0.0	29.8	-0.0	-0.0	0.00	244.83	-0.00	111.2
9	G	9.8	0.0	30.2	-0.0	0.0	-0.00	224.45	0.00	103.9
10	G	9.8	0.0	30.6	0.0	-0.0	-0.00	204.07	-0.00	96.6
						Section:	8,	from: P70	to: FSE	
0	G	9.8	0.0	30.6	0.0	-0.0	-0.00	204.07	-0.00	96.6
1	G	9.8	0.0	30.9	-0.0	-0.0	0.00	183.68	-0.00	89.3
2	G	9.8	0.0	31.2	-0.0	0.0	-0.00	163.28	0.00	82.0
3	G	9.8	0.0	31.5	-0.0	-0.0	0.00	142.88	-0.00	74.8
4	G	9.8	0.0	31.7	-0.0	0.0	-0.00	122.48	0.00	67.5
5	G	9.9	0.0	31.9	-0.0	-0.0	0.00	102.07	-0.00	60.2
6	G	9.9	0.0	32.0	-0.0	0.0	-0.00	81.66	0.00	52.9
7	G	9.9	0.0	32.2	-0.0	-0.0	0.00	61.25	-0.00	47.2
8	G	9.9	0.0	32.2	-0.0	0.0	-0.00	40.84	0.00	47.2
9	G	9.9	0.0	32.3	-0.0	-0.0	0.00	20.42	-0.00	47.2
10	G	9.9	0.0	32.3	-0.0	-0.0	-0.00	0.00	0.00	47.2

Minimum route radius

Extract of results (max. values)

1. PUR-foam and jacket pipe

ANR - Section number
TAUPUR - PUR-Shear tension in MPa
SIGPUR - PUR-Pressure tension in MPa
Other characteristics as before
tEC - thick.exp.cushion in mm

ANR	KZ	FRg'	TAUPUR	Q'(v)	SIGPUR exist.	SIGPUR all.	tEC
1	G	-1.5	-0.001	0.0	0.0000	0.1500	0
2	G	-6.0	-0.006	0.0	0.0000	0.1500	0
3	G	-5.7	-0.006	-4.5	0.0138	0.1500	0
4	G	-2.2	-0.002	-20.8	0.0641	0.1500	0
4	B	18.5	0.018	-29.9	0.0923	0.1500	0
5	G	9.8	0.010	-3.6	0.0110	0.1500	0
6	G	9.8	0.010	-2.6	0.0080	0.1500	0
7	G	9.8	0.010	0.0	0.0000	0.1500	0
8	G	9.9	0.010	-0.0	0.0000	0.1500	0
Allow. values			0.030				

2. Steel pipe
2.1. Max. surrounding tension from inner pressure and annul.bending

PHI	- angle in segment in degr
P	- inner pressure in bar
SIGT(P)	- circum. tension caused by inner pressure in MPa
SIGT(Rb)	- circum. bending stress caused by lateral compression in MPa
SIGT	- SIGT(P) + SIGT(Rb)
all. SIGT	- allowable tangential stress in MPa

ANR	SNR	KZ	PHI	P	SIGT(P)	SIGT(Rb)	SIGT	all. SIGT
4	8	B	270	0.00	0.0	45.6	45.6	156.7
4	8	B	270	16.00	45.6	45.6	91.3	156.7

2.2. Detailed stress analysis
at the location with the max. reference stress

Stress determination and assessment based on ASME und AD-S2

The maximum reference stress occurs at

ANR	SNR	KZ	PHI	FIBRE
4	1	B	270	outer

Type of stress (in MPa)	i	SIG..
Nom. stress caused by int. pressure	1.0000	45.63
Tangential stress		67.50
Axial stress		-243.68
Radial stress		0.00
Circumferential bending stress	-0.0702	21.87
Total stress		311.18
allowable value		909.00

2.3. Axial stress caused by friction

The maximum axial stress amounts to 106.45 MPa und occurs in:

ANR	SNR
4	13

The allowable axial stress of 190.00 MPa is not crossed.

IEA District Heating and Cooling

BEND-PIPES

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