On the theoretical axial resistance of district heating joints

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Abstract

District heating networks consist of different pipe segments, straight pipes, pipe bends and T-branches, which are connected on site. A large number of connections must therefore be made in order to create a branched district heating network. In this paper the state of art in pipeline engineering is reviewed and analyzed for the determination of the theoretical axial resistance of district heating joints, since an anchor effect of the joints was expected. Based on the findings a calculation method for the expected resistance is proposed and in a parameter study the deviations to a straight pipe are shown for typical joint applications.

Keywords: District heating construction, District heating joints, axial resistance

Introduction

District heating networks consist of different pipe segments, straight pipes, pipe bends and T-branches, which are connected on site. A large number of connections must therefore be made on site to create a branched district heating network. This is particularly the case with typical rigid pipe segments in accordance with EN 253 [EN253:2024] and EN 488 [EN488:2025], as pipes with a maximum length of 6 or 12 meters are mainly used for straight sections. The structure of a district heating pipe connection is shown in Figure 1.

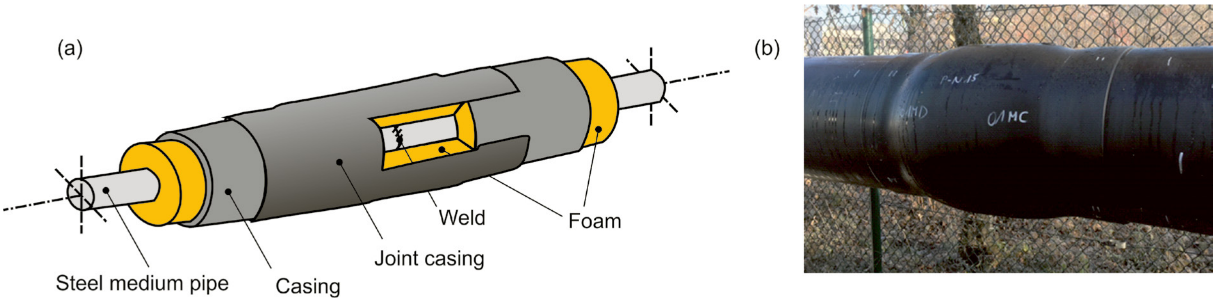

Figure 1. District heating joint system, (a) technical scheme, (b) Foto

The pipes and connections are subjected to a combination of primary loads due to temperature and internal pressure and secondary reaction loads due to the interaction between the pipe and the ground.

The load level according to EN 13941 [EN 13941:2022] and EN 253 with peak temperatures of up to 120°C of the medium and an internal pressure of up to 25 bar can be safely operated if all pipe static verifications have been carried out according to EN 13941. Axial earth resistance is particularly important in calculations for pipe statics, as almost all verifications depend on its quantity. The temperature-related expansion of the pipes is partially constrained by the axial bedding reaction, which results in smaller displacements and bending moments in the curved areas, while the axial stresses in the pipe are significantly lower than in fixed systems due to the permitted movements. This makes it possible to achieve an economical design despite high loads. The key relationships between pipe statics and soil mechanics phenomena are explained in [ACHMUS & WEIDLICH 2016].

Normatively, a constant line load is applied for the calculation of the axial reaction stress, which corre-

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sponds to friction, particularly in granular backfill materials. Figure 1 shows that joints can have larger diameters than straight pipes. The change in diameter leads to increased resistance during axial displacement, which is not reflected by a constant line load that relates solely to the straight pipe. A theoretical calculation approach for the axial bedding reaction resistance for district heating joint systems is developed below.

Methodology

In this paper the state of art in pipeline engineering is reviewed and analysed for the determination of the theoretical axial resistance of district heating joints. Based on the findings a calculation method for the expected resistance is proposed. In a parameter study the expected results and deviations to a straight pipe are shown for typical joint applications.

State of knowledge

Changes in direction, elongation compensation elements, branches, diameter changes and the integration of other components in district heating networks require connections. The construction of the connection results in a change in cross-section compared to a straight pipe. The geometric changes usually occur in the course of the manufacturing process on site due to the internal pressure generated during foaming and the high temperatures of the exothermic foaming reaction, which soften the casing. The change in diameter increases soil resistance during temperature-induced movements throughout subsequent operation. According to EN 253 from 1994, the average outer diameter of the casing must not increase by more than 2% [EN 253:1994]. According to AGFW code of practice FW 401 T14, an increase in diameter of 2% is therefore also considered permissible for the connection area and the joint casing. Today, this requirement no longer exists in the current version of EN 253:2024. Since the EN 253:2015-12 version, only minimum and maximum values for the diameter of the casing are specified. The specifications refer to the composite pipe system and include manufacturing tolerances, including the increase due to foaming.

According to GRAGE and HERBST, the formation of these connections can lead to either an increase or a decrease in cross-sectional area [GRAGE & HERBST 2013]. In some single cases no difference between the cross sections is observed. Figure 2 illustrates the joint shape factor ξ according to Equation 1. GRAGE and HERBST report joint shape factors for DN 80/160 of $\xi = 0.96$ (decreased joint diameter) to $\xi = 1.17$ (increased joint diameter) and for DN 150/250 of $\xi = 0.97$ to $\xi = 1.12$.

$$\xi = \frac{D_J}{D_P} \qquad \text{Equation 1}$$

Where ξ =Shape factor, D_J=Joint Diameter, D_P=Pipe Diameter.

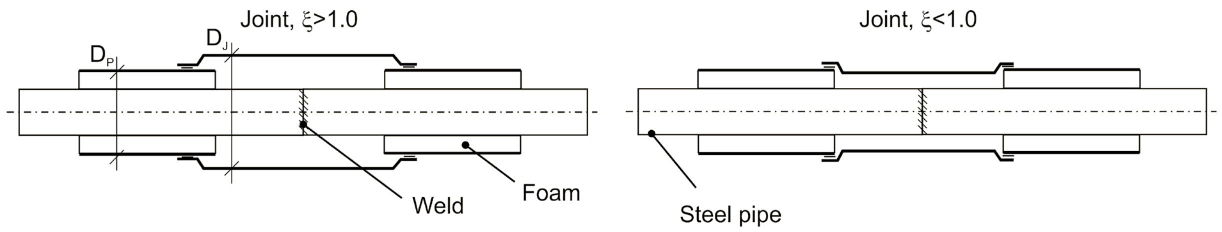

Figure 2. cross sections at the joint

Decreased joint diameters are not allowed according to FW401 Part 14, because this is an indicator of insufficiently foamed joints or an incorrect mixing ratio of the foam components [FW 401 P14:2007]. Thus, the increased diameter at the joint is the more relevant here. An increase factor ξ_i according to EN253:1994 can be defined according to Equation 2.

$$\xi_i = \frac{|D_j - D_P|}{D_P} < 2\% \qquad \text{Equation 2}$$

At HafenCity University, as part of quality assurance tests on DN 80/160 DH-pipes, the foaming process was measured and the joint temperatures and diameter changes were determined [ANDRETZKY et al. 2024]. It was found that during foaming, temperatures rise by up to 20 Kelvin compared to the initial state and can reach temperatures of up to 40°. At the same time, the joint casing expands significantly, but the permanent deformations are smaller after subsequent cooling than during foaming. After the connections had been made, the joint shape factors were determined for five different types in the project. They varied for the nominal diameter DN 80/160 in the range from ξ=1.10 to 1.21. Figure 3 shows a comparison of the permissible form factors derived from AGFW FW401 Part 14, Table 1, with the measured values. It can be seen that higher tolerances result for small diameters than for large diameters. Permissible values for joint diameters below DN 80 base pipe are not specified.

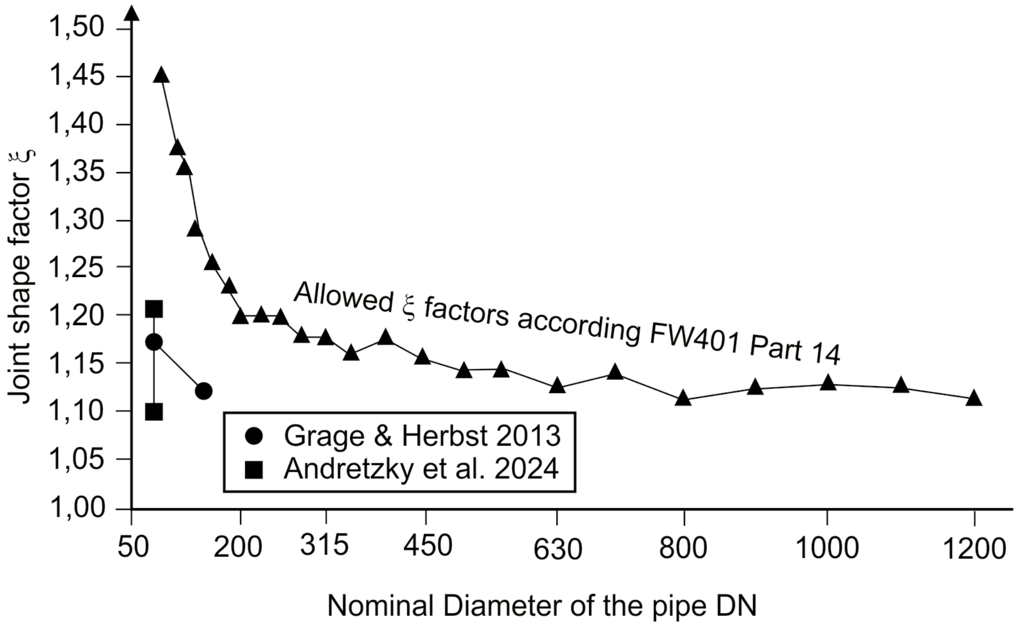

Figure 3. Joint shape factor ξ in comparison

Axial bedding reaction occurs in plugged sewer-pipe connections when there is relative movement between the pipe and the ground. This is phenomenologically comparable to the axial resistance of a district heating joint connection. NETZER and HELBIG describe according to figure 4 in [NETZER & HELBIG 2018] the resistance R_J of the joint according to Equation 3 using the earth pressure coefficients according to RANKINE.

$$R_J = \frac{\pi}{4}\left(D_j^2 - D_C^2\right) \cdot \gamma_s \cdot H \cdot \left(K_p - K_a\right) \qquad \text{Equation 3}$$

Where:

R_J=axial soil resistance of the sewer joint due to the diameter difference

D_J=Joint Diameter

D_P=Outer Pipe Diameter

γ_S= weight of the soil

H = Overburden height of the pipe axis

K_P= passive earth pressure coefficient according to RANKINE

$$K_p = \frac{1 + sin\varphi'}{1 - sin\varphi'}$$

φ' = internal friction angle

K_A = active earth pressure coefficient according to RANKINE

$$K_a = \frac{1 - sin\varphi'}{1 + sin\varphi'}$$

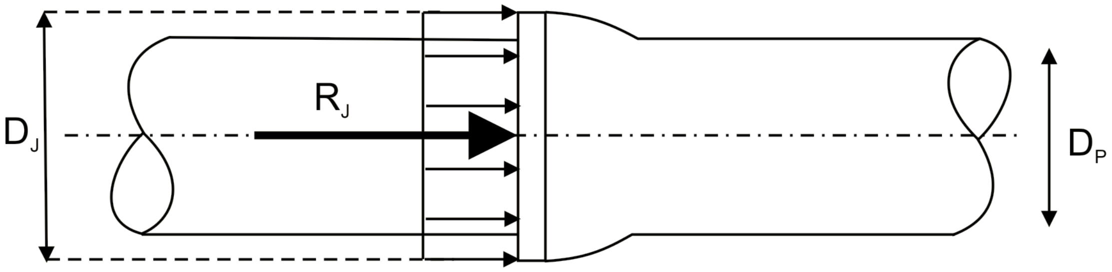

Figure 4. Soil resistance at a sewer joint according to NETZER and HELBIG

Consequently, additional axial bedding resistance must also be expected in district heating pipes if they move axially in the ground as a result of the increased diameter at the joint. In addition, the axial bedding reaction resistances on straight pipes are a function of the diameter. This can be seen in equation 4 according to [ACHMUS & WEIDLICH 2016] for the calculation of axial soil resistance with the K_0-method. A bigger diameter then applies for the joint section.

$$R_f = \gamma_s \cdot H \cdot \left(\frac{1 + K_0}{2}\right) \cdot \pi \cdot D \cdot L_J \cdot \mu \qquad \text{Equation 4}$$

Where:

R_f=axial soil resistance

γ_s = weight of the soil

H = Overburden height to the pipe axis

K_0= earth pressure coefficient at rest = 1-sin φ'

φ' = internal friction angle

D= Diameter

L_J= length of the joint

μ = coefficient of friction between the casing and surrounding soil

The total resistance at the joint R_{tot} is illustrated in Figure 5.

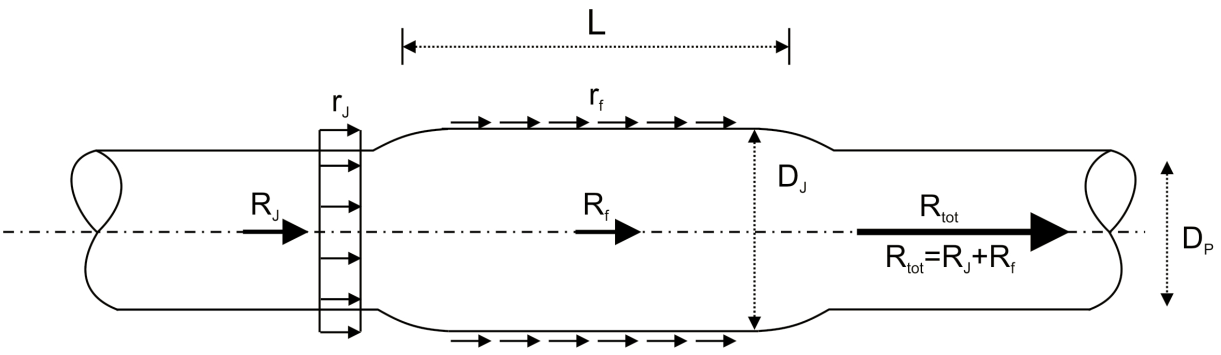

Figure 5. Total axial soil resistance at the joint

The length of the joint is determined by the free steel pipe length required for welding and an overlap on the base pipe. Typical delivery lengths from manufacturers range from 700 mm to 1000 mm; lengths of 605 mm to 805 mm were measured at HCU. For straight DH pipes with a length of 6 m to 12 m, the connections thus account for approx. 10% of the 6 m pipe and 5% of the 12 m pipe in the construction.

Results

The above explanations show that the resistance during axial displacement of the joint is determined by the diameter difference and the additional friction at the joint due to its larger diameter. The combination of Equation 3 and 4 results in Equation 5.

$$R_{tot} = \gamma_s \cdot H \cdot \pi \left[\left(D_J^2 - D_P^2\right) \cdot \frac{\left(K_p - K_a\right)}{4} + \left(\frac{1 + K_0}{2}\right) \cdot D_J \cdot L_J \cdot \mu \right] \qquad \text{Equation 5}$$

In order to gain a better impression of the magnitude of the additional forces resulting from the increased diameter of the joint, a parameter study was carried out using the parameter set shown in Table 1, and the additional forces were normalised by introducing the indicator I_{plus} of increased forces according to Equation 6. The results are shown in Figure 6.

Parameter	Symbol	Value
Length of the base pipe	L_B	6 m
Length of the joint	L_J	$0.1 * L_B$
Overburden height to the pipe axis	H	1.5 m
Internal friction angle	φ'	32.5°
Friction coefficient PE-Sand	μ	0.4
Weight of the soil	γ_s	20.0 kN/m³
Joint shape factor	ξ	Allowed shape factor derived from AGFW FW401 Part 14

Table 1: Parameter set for calculation example

$$I_{plus} = \frac{R_{tot} + 0.9 \cdot R_{f,B}}{R_{f,B}} \qquad \text{Equation 6}$$

Where:

R_{tot}=total axial soil resistance of the joint system

$R_{f,B}$=axial soil resistance of the base pipe according to Equ. 4 with $D = D_P$

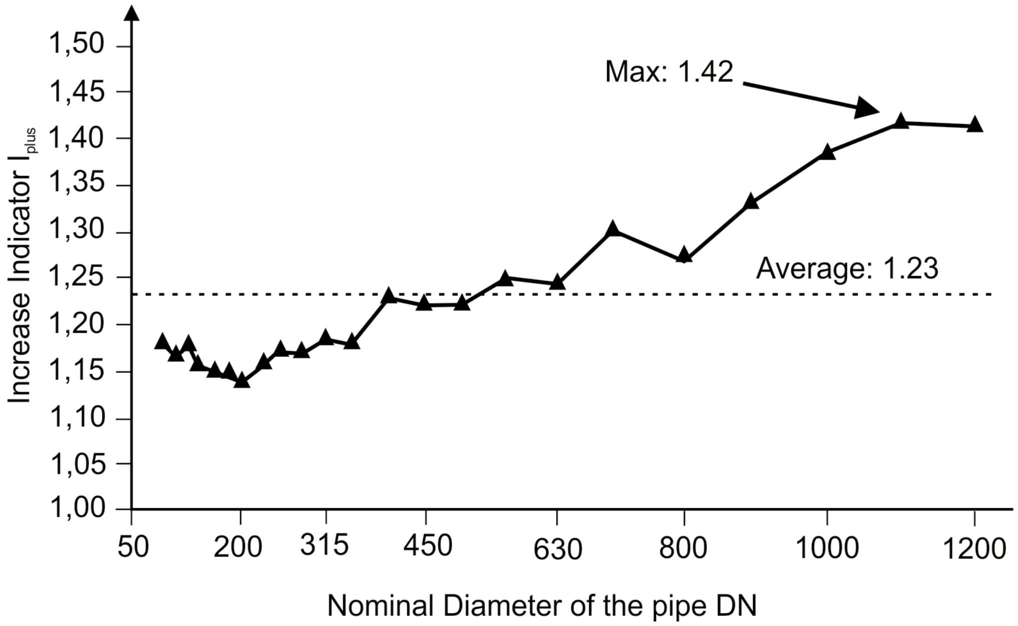

Figure 6, Results of the parameter study

Discussion and Conclusion

In this study, common calculation methods from pipe engineering are used to provide a theoretical basis for calculating joint resistance in the event of axial pipe displacement. This allows the increase in displacement resistance to be estimated for known joint geometry. In particular, the diameter of the joint casing must be known in order to perform a calculation. A parameter study with a soil cover of 1.5 m above the pipe axis and the permissible diameter changes at the joint casing according to FW401 T14 showed that the resistance increases significantly. Based on a 6 m pipe, normalised indicators for increased forces of up to 1.42 maximum and 1.23 average were obtained. The results apply to large axial displacements in which passive earth resistances are fully developed (K_p approach according to RANKINE). With small displacements, the anchor effect of the joint is lower. Furthermore, the permitted diameter changes according to the AGFW code of praxis appear to be much higher than observed values. Because of its limits these theoretical considerations must be validated by measurements. Sandbox tests according to type testing in accordance with EN 489 [EN 489:2022] seem to be unsuitable for this purpose, as constraints and related stresses arise in the small sandbox that are atypical for the actual installation situation in situ. An evaluation should therefore be carried out on field measurements that are more realistic. Furthermore, the proposed calculation approach is only applicable to monotonic initial displacement. The alternating loads that typically occur in district heating pipes are not taken into account here. The calculation approach must therefore be expanded in order to fully capture the phenomenon.

Acknowledgements

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