Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 95 (2016) 11 – 16

Energy Procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2015, 14-16 October 2015, Riga, Latvia

Near future testing requirements for joints in modern district heating networks

Ingo Weidlich*

Fernwärme Forschungsinstitut, 30966, Max-von-Laue-Str. 23, Hemmingen, Germany

---

Abstract

Due to manual installation of joints, the connection of the single pipe segments is one major influence for the performance of the whole network system. For granting joint quality, minimum requirements have to be proven in a standardized European test. Recommendations for the improvement of the test procedure are given. Furthermore expected operational loads in modern district heating networks are discussed. Since flexible operation of combined heat and power plants is necessary due to peak loads from feeding in of renewable energy sources, a different load spectrum is expected for the district heating network in the future. Possible amendments for the testing may be derived and a first step for understanding the load spectrum of joints in modern district heating networks is discussed.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.

Keywords: district heating networks; joints; sand box; load spectrum

---

1. Introduction

For reliable modern district heating (DH) networks, sustainable solutions for their construction is needed. The joint technology is a key factor for quality and serviceability.

Due to manual installation of the joints, the connection of the single pipe segments is one major influence for the performance of the whole network system. For granting supply to the customer and low heat losses in the system, high requirements are necessary for the quality of joints [1]. Since there are several joint systems on the market, quality

---

* Corresponding author. Tel.: +49511943700
E-mail address: weidlich@fernwaerme.de

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment.
doi:10.1016/j.egypro.2016.09.003

testing in a sand box was established and standardized in the European Standard EN 489 [2]. The boundary conditions for the tests were chosen close to the estimated operational load for district heating pipes during a lifetime of 30 years. However, a longer lifetime for the pipe system was suggested according to investigations of other authors [3]. On the other hand, the future load spectrum for pipe systems is assumed to imply more repeated temperature loads and an overall lower temperature level. These reverse acting effects are not well understood today. An accurate life-cycle-analysis seems to be difficult for the district heating networks and their joints because of unsolved uncertainties. The meaning of the results according to EN 489 should be reviewed.

Nomenclature

C_U	uniformity index
D_r	relative density
e	void ratio

Due to manual installation of the joints, the connection of the single pipe segments is one major influence for the performance of the whole network system. For granting supply to the customer and low heat losses in the system, high requirements are necessary for the quality of joints [1]. Since there are several joint systems on the market, quality testing in a sand box was established and standardized in the European Standard EN 489 [2]. The boundary conditions for the tests were chosen close to the estimated operational load for district heating pipes during a lifetime of 30 years. However, a longer lifetime for the pipe system was suggested according to investigations of other authors [3]. On the other hand, the future load spectrum for pipe systems is assumed to imply more repeated temperature loads and an overall lower temperature level. These reverse acting effects are not well understood today. An accurate life-cycle-analysis seems to be difficult for the district heating networks and their joints because of unsolved uncertainties. The meaning of the results according to EN 489 should be reviewed.

2. Sandbox testing according to EN 489

2.1. Testing methodology

The testing methodology for joints according to EN 489 was introduced in terms of a maximum load test. A sand box test was selected to represent *in situ* trench conditions and a load spectrum for an estimated lifetime of 30 years was chosen. For the joint system the following general requirements are defined according to EN 489 [2]:

- Resistance against axial forces due to axial displacement of the test specimen;
- Resistance against radial forces and bending moment (not tested in the sand box);
- Resistance against temperature influence and temperature changes;
- Water tightness.

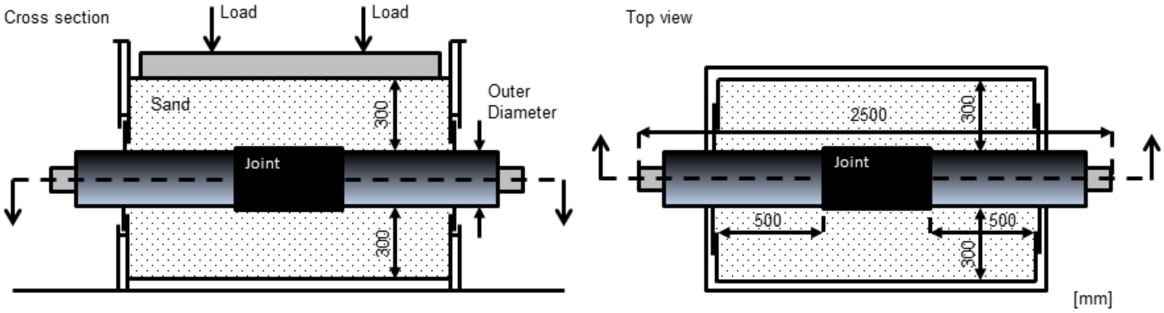

Fig. 1. Scheme of the sand box according to [2], cross section (left), top view (right).

Water tightness is tested only when the sand box test is passed. A scheme of the minimum geometry of the sand box is given in Fig. 1. In this sand box a district heating pipe with minimum length of 2500 mm including the joint is installed in dry sand. The moisture content of the sand must be lower than 0.5 % and a grain distribution curve within the boundaries shown in Fig. 2 has to be granted. In Europe the determination of the grain-size distribution curve is standardized according to EN 933-1 [4]. The sand body is covered optionally by a rigid plate with additional loads that represent an overburden pressure at the pipe axis. The following test parameters have to be met:

- Temperature of the medium pipe of 120 °C;
- Overburden height, real or simulated, of 18 kN/m^2;
- Cyclic displacement of 75 mm;
- Displacement rate 10 mm/min forward;
- Displacement rate 50 mm/min backward.

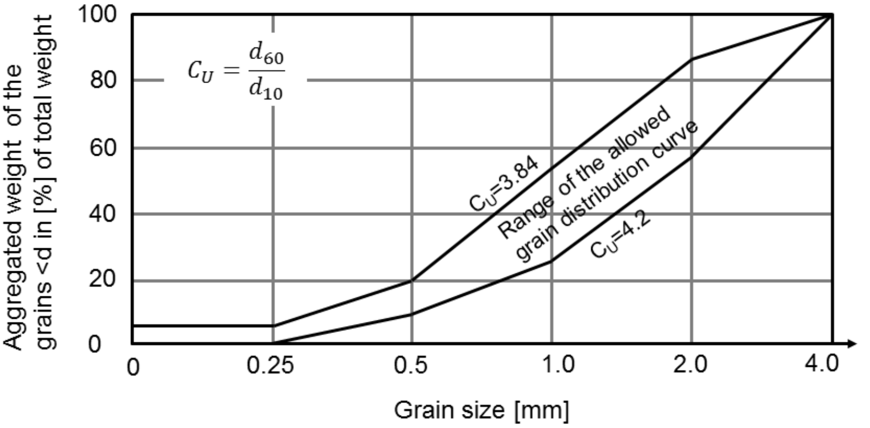

Fig. 2. Range of the allowed grain distribution curve according to [2].

3. Preparation of sand specimens for sand box tests

The methodology of the preparation of sand specimens for sand box installation is not explained in EN 489. However, the preparation methodology of sand specimens has the main influence on the results and several installation methods were investigated by different authors [5–11]. Each sand test specimen has to be prepared individually.

3.1. State of compactness

The state of compactness is an important index property for stiffness and firmness of reconstituted sand specimens. Sands are cohesionless soils with coarse grains in the diameter size range of 0.06 mm to 2 mm [4]. The state of compactness is expressed for cohesionless soils by the relative density D_r according to Equation 1.

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \cdot 100 \, [\%] \tag{1}$$

The preparation of repeatable relative densities in sand specimens is a major challenge in geotechnical testing according to Butterfield and Andrawes [5]. Nevertheless the control of the relative density is very important to avoid significant deviation in test results.

3.2. Preparation methods

The common objectives for preparation methods are homogenous soil samples and repeatable density. Two general preparation methodologies are known [7]. The required density is achieved either during the installation process or after. Methods that imply compaction for the required density after the sand installation are tamping, moist tamping and vibration. Specimens produced with these kind of methods tend to be less uniform and should be used only for dense specimens [7]. If tamping is used, grain fracture may occur and the grain distribution curve is changed [6]. Furthermore tamping often leads to deviating density with the depth. Because of this, and due to the memory effect of sands, pouring methods for sand preparation are recommended in literature [5–11]. The equipment for pouring and testing must be calibrated together with the used sand. The sand particles fall by gravity from the height of drop on the surface of the sand specimen. With pouring equipment repeatable dry specimen may be produced as well as water saturated specimen. Water saturated sand specimens are not considered in this article.

For air pluviated sand specimens density is controlled by the height of drop and the mass rate of pouring. The mass rate is the mass of sand poured per time unit. For a given sand and volume to be filled, the height of fall and mass rate of pouring appeared to have opposite effects [7]. For constant mass rate the density of a specimen increases with increasing height of drop until an ultimate height of drop is reached. Then density can only be increased by lowering the mass rate.

The influence of the mass rate on the density was investigated by Cresswell et al [8]. Density of the soil specimen seemed to depend on the movement of the single particle during the pouring, where the minimum kinetic energy for the position and the impact from other particles at deposition seemed to be the two most influencing factors. Just above the deposited sand layer, a thin layer, 3 to 4 grains thick, of actively moving grains called "the energetic layer" was observed. The movements are mainly within the horizontal plane. Above the energetic layer, a saltation zone of up to 20 mm of bouncing grains ejected from the energetic layer or rebounding falling grains was visually identified. The pouring method may thus be explained according to Fig. 3.

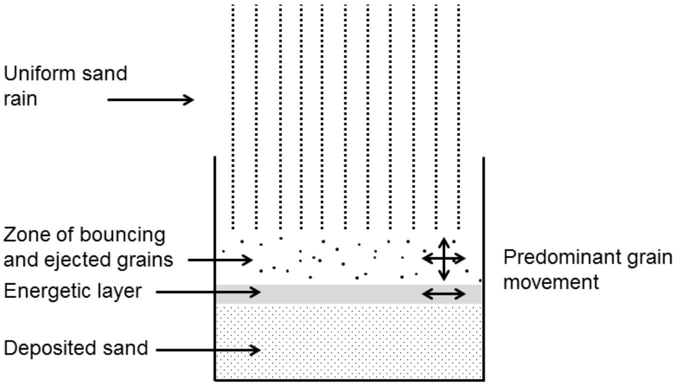

Fig. 3. Particle movement according to [8].

Additional factors influencing the density during pouring are the "viscosity of the fluid" (here it is a mixture of air, sand and powder), the dissipation of kinetic energy by friction between the particles and boundary walls according to Lo Presti et al. [6]. Different pouring methods can be found in the literature as for example direct pouring from a tube, sand rain, sand curtain and others [9–12].

4. Near future load spectrum

A growing share of renewable energy can be noted in European energy markets. Because of this, flexible operation of combined heat and power plants is necessary [13]. For the connected district heating network this means future additional temperature changes in the system, which is a higher requirement for the network. On the other hand heat losses may be reduced by a lower temperature of the heat carrier [14]. Thus future district heating network may be operated at a lower temperature level. A lower temperature level implies a lower load for the network and its components. These reverse acting effects are not well understood today.

Today the structural analysis for district heating components of the network is regulated in great parts according to EN 13941 [15]. According to this standard, the ultimate limit states A1 and A2 for one severe action and few actions, respectively. B1 and B2 indicate low cycle fatigue and high cycle fatigue and have to be respected. Furthermore limit states C and D are defined. Repeated loading in the system has to be respected in the fatigue analysis. For a suggested lifetime of a district heating network of 30 years an estimated number of cycles for the temperature load was accumulated. In Table 1 the estimated equivalent action cycles for state of the art district heating pipes are shown according to EN 13941.

Table 1. Equivalent action cycles according to EN13941 [15].

Pipe type	Equivalent full load action cycles in 30 years according to EN13941
Major pipelines	100
Main pipelines	250
House service connections	1000

For the equivalent action cycles according to Table 1, only the safety against low cycle fatigue B1 is to be verified. For conventional district heating pipes, the limit state B2, high cycle fatigue, is only of importance in the case of large diameter pipe, small soil cover and heavy traffic actions or pipes above ground subject to vibration, e.g. from wind. Then EN13941 refers to Eurocode 3 (EN 1993 [16]), Structural Use of Steel, for high cycle fatigue analysis, which is relevant, for example, for solar thermal pipes with more than $N = 10^4$ cycles.

Nevertheless a longer lifetime than 30 years for district heating pipes is expected in the district heating sector [3], which also means higher cyclic loading. Furthermore the numbers of Table 1 only give a general characteristic for district heating networks. Due to individual operation parameters and individual network conditions, the equivalent action cycles are expected to be different at every element in the network.

This leads to the evidence that accurate life-cycle-analysis seems to be difficult for future district heating networks because only rough estimated load spectra are available.

5. Results

The review of test methods for geotechnical investigation leads to several results. For accurate and comparable test results homogenous and reproducible soil specimens with such density are necessary. The preparation of reproducible specimen is demanding and should be defined as accurate as possible. However, in the European Standard EN 489 the preparation method for the sand specimens is not fixed or explained. Because of this it is strongly recommended to define the preparation method and the required density for the soil [17]. Since dense compaction is typical for *in situ* trench backfill, dense sand specimen for the test should be requested. Dense to very dense compaction is represented by a relative density D_r in the range of 70 % to 100 %, which is still a wide range. For adequate comparability of results, a limited bandwidth of D_r=80 – 85 % is proposed here.

Additional difficulties are expected for the making of sand specimens with repeatable properties, which surround structural elements. Because of the interaction between rigid bodies and the sand during installation less compacted areas are to be awaited close to these bodies. Using pouring methods, some sand rain shadow might occur behind the structural element to be tested. Convincing results by pouring methods thus may be costly and difficult to achieve with an economic perspective. On the other hand reproducibility of soil interaction tests is very important for the credibility.

The analysis of near future load spectra for district heating networks and its components shows that changes are to be expected. Increased cyclic loading and decreasing temperature loads are assumed for future district heating networks. The consequences of these changes in the load spectrum are not well understood today. This notified background gives reason to review the testing parameters of the sand box test according to EN 489. Suggested points of discussion are:

- Temperature of the medium pipe below 120 °C;
- Definition of the installation method and specification of the required density for the sand specimen;
- In situ conditions of the backfill may not be covered by a moisture content below 0.5 % and a maximum grain diameter of 4 mm;
- Operating conditions may not be represented by a maximum cyclic displacement of 75 mm and the displacement rates 10 mm/min forward, displacement rate 50 mm/min backwards;
- Increased expectation for the duration of serviceability of components (more than 30 years).

6. Conclusion

Since the joint technology is a key factor for the performance of district heating networks future developments in the energy sector should also be respected in the elaboration and adaption of EN 489. Furthermore existing scientific evidence for the installation of sand specimen should be taken into account to increase credibility of the results. On the other hand only economic testing makes an efficient quality assurance possible. It is recommended to take these aspects into account and find a balance.

References

[1] Besier R, Plott A. AGFW Schadensstatistik KMR 2004. Euroheat & Power 2005;34(9):62−67.
[2] EN 489:2009 District heating pipes - Preinsulated bonded pipe systems for directly buried hot water networks - Joint assembly for steel service pipes, polyurethane thermal insulation and outer casing of polyethylene.
[3] Hoffmann HW, Grage T, Röse A. Remaining useful life of pre-insulated bonded pipes. Euroheat & Power 2002;31(3):72−76.
[4] EN 933:2012 Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution – Sieving method.
[5] Butterfield R, Andrawes KZ. An air activated sand spreader for forming uniform sand beds. Géotechnique 1970;20:97−100.
[6] Lo Presti DCF, Pedroni S, Crippa V. Maximum Dry Density of Cohesionless Soils by Pluviation and by ASTM D 4253-83: A Comparative Study. Geotechnical Testing Journal 1992;15(2):180−189.
[7] Vaid YP, Negussey D. Preparation of reconstituted sand specimens. Advanced Triaxial Testing of Soil and Rock 1988:405−417.
[8] Cresswell A, Barton ME, Brown R. Determining the Maximum Density of Sands by Pluviation. Geotechnical Testing Journal 1999;22(4):324−328.
[9] Rad NS, Tumay MT. Factors affecting sand specimen preparation by raining. Geotechnical Testing Journal 1985;10(1):31−37.
[10] Walker BP, Whitaker T. An apparatus for forming uniform beds of sand for model foundation tests. Géotechnique 1967;17:161−167.
[11] Fretti C, LoPresti DCF, Pedroni S. A Pluvial Deposition Method to Reconstitute Well-Graded Sand Speciments. Geotechnical Testing Journal 1995;18(2):292−298.
[12] Chen HT, Lee CJ, Chen HW. The travelling pluviation apparatus for sand specimen preparation, Centrifuge´98, Klimura, Kusakabe & Takemura (Hrsg.). Balkema: Rotterdam; 1998.
[13] Holler S. Prospects and challenges of thermal energy storage in future energy systems. Environmental and climate technologies: conference proceedings 2013:27−30.
[14] Vigants G, Blumberga D. Modelling of the district heating system's operation. Environmental and Climate Technologies 2011;6(13):132−137.
[15] EN 13941:2010 Design and installation of preinsulated bonded pipe systems for district heating, DIN, Deutsches Institut für Normung e.V. Normenausschuss Heiz- und Raumlufttechnik (NHRS).
[16] EN 1993:2010 Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. German version EN 1993-1-1:2005 + AC:2009.
[17] Achmus M, Brachetti HE, Grage T. Anmerkungen zur Erddruckprüfung gemäß prEN 489. Euroheat & Power – Fernwärme international, 2001.