Test Series on the Desiccation Behaviour of Sand and Thermally Stabilizing RSS Flüssigboden® TS

according to

RAL-GZ 507

at a set temperature of 90°C
(temperature on the contact surface
between heat source and bedding material)

Project: basic research

FiFB – Forschungsinstitut für Flüssigboden GmbH

	Version 1	Revision 1	Revision 2
Date	07 July 2017		
Document number	GF.17.056.2017621V0.7		
Internal project number	17-056/008-17		
External project number	zu 70019952		
Creators	J. Detjens, O. Stolzenburg		
Translator			
Reviewer			
Signature			
approved by	O. Stolzenburg		
release Signature			

Contact persons		
Forschungsinstitut für Flüssigboden GmbH (FiFB)	Jürgen Detjens	(+49) 341 244 69 11 j.detjens@fi-fb.de
	Olaf Stolzenburg	(+49) 177 959 3041 o.stolzenburg@fi-fb.de

Table of Contents

I. List of Abbreviations

BCE	cement-based accelerator
CEM I 42,5 R	cement type according to DIN EN 187-1
IM	inherent moisture
E_U	modulus of elasticity at maximum slope of the tangent according to DIN 18136
E_{U50}	modulus of elasticity at 50% compressive stress according to DIN 18136
E_{U30}	modulus of elasticity at 30% compressive stress according to DIN 18136
FB	RSS Flüssigboden TS
FBC	Flüssigboden Compound (additive for RSS Flüssigboden)
FBC-TS	special Flüssigboden Compound for the production of thermally stabilizing RSS Flüssigboden based on clay
FiFB	Forschungsinstitut für Flüssigboden GmbH
ha	initial hight of a test sample before testing the unconfined compressive strength according to DIN 18136
m wt	moist weight of a sample
d wt	dry weight of a sample
qu	unconfined compressive strength according to DIN 18136
RSS Flüssigboden	liquid soil with defined additives; according to mix designs of FiFB or Logic Logistic Engineering GmbH
RSS Flüssigboden TS	special liquid soil for thermal stabilizing of warm conduits, such as GIL tubes and electric cables, with defined additives; according to mix designs of FiFB or Logic Logistic Engineering GmbH
RW	name of the construction material tester (Mr Raymond Wänke)
SE	uniform-graded sand Sand according to DIN 18196
UP 25/50	universal testing press with 25 resp. 50 kN force absorption, path-controlled
ε	strain according to DIN 18136
Δh	hight change of a sample before/after testing the unconfined compressive strength according to DIN 18136

II. List of Figures

III. List of Tables

1. Inducement

The development and the establishment of the liquid soil method (RSS Flüssigboden method) for important new applications have always been connected to extensive basic research, from the beginning in 1997/1998. For the application of thermally stabilizing RSS Flüssigboden (RSS Flüssigboden TS), the material behaviour of the RSS Flüssigboden at different, especially high temperatures of a heat source (GIL tubes and underground cables) must be examined. Thermally stabilizing Flüssigboden TS is supposed to dissipate as much heat as possible, ie to ensure a maximum heat flux, also called thermal output. The RSS Flüssigboden method makes it possible to adapt the heat dissipation capacity (thermal output) of RSS Flüssigboden to the requirements of the respective cable route, even though the characteristics of the source materials (different soil types) may be very different, by applying an adequate mix design, and hence influencing relevant material properties.

The purpose of this test is to examine the temporal constancy of the inherent moisture at a defined temperature. This test is particularly meant to simulate the worst case situation of the material placed in situ (ie 90°C surface temperature of the heat source) for the application of GIL tubes in the project "Dunford bridge UK".

RSS Flüssigboden TS is not a product in the sense of a production from always the same source material, but it rather is the result of the application of the liquid soil method with very different types of soil being used as source materials. The applied source materials may have very different heat conductivities and other varying properties.

In the conducted test, the verification of non-appearance of desiccation in thermally stabilizing RSS Flüssigboden TS is limited to one particular composition, ie one mix design.

2. Principle of the test

A heat source constantly heats an approx. 80cm layer of RSS Flüssigboden TS for a period of 47 days at high temperatures. The heat source is a ¾ inch galvanised customary steel tube heated to approx. 90°C surface temperature by a glass fibre heating tape with a digital heating controller (figure 2). A temperature sensor in the steel tube controls the temperature. The temperature is recorded at defined intervals. To minimise the complexity of this test we decided to refrain from an additional error analysis of the rather small temperature fluctuations.

The heat source is activated at least 28 days after the production of the RSS Flüssigboden TS, when the adhesion and adsorption processes of the added water have with certainty reached a permanent and stable state. The RSS Flüssigboden TS was places in the sewage pipes (OMNIPLAST sewage pipe PVC-U OD 160) on 28 March 2017. A customary sand SE (see grain size distribution, figure 4) was used as an easily comparable source soil with originally poor water retention.

Sand was selected as source material as we presumed the rather low capillary pressure of sand is suitable to simulate a worst-case scenario. The employed mix design has a composition typical for this kind of material and application. In the conducted test, the Compound type „FBC-TS 3“ was applied. In order to simulate in situ conditions, the liquid soil is filled in a 2m sewage pipe. The pipe is positioned vertically with the lower end embedded in a mortar trough filled with the same source material (figure 1). In the pipe, the structure of the soil layers, including the structure of the bedding material of the trench, can be simulated.

The mortar trough was half filled with the source material which was then manually compacted. The density of the placed material was not examined. Three sewage pipes were based on the manually compacted material and fixed on a wall to make the system more stable. Then, a layer of approx. 40cm of the source material was placed in two of the three pipes and compacted manually, again. Then, a layer of thermally stabilizing RSS Flüssigboden TS of about 80cm was placed.

24 hours after the placement of the liquid soil, the pipes were filled with RSS Flüssigboden TS up to about 10cm below the top edge of the pipe, and compacted manually. Density and compaction levels were not examined. The third pipe was completely filled with the source material, ie without any RSS Flüssigboden TS.

To simulate a defined inherent moisture of the surrounding ground, the source material was conditioned 5% of inherent moisture. We assume that under the climatic conditions in Central Europe the inherent moisture (IM) of 5% is a minimum value, and so a worst-case scenario is simulated here.

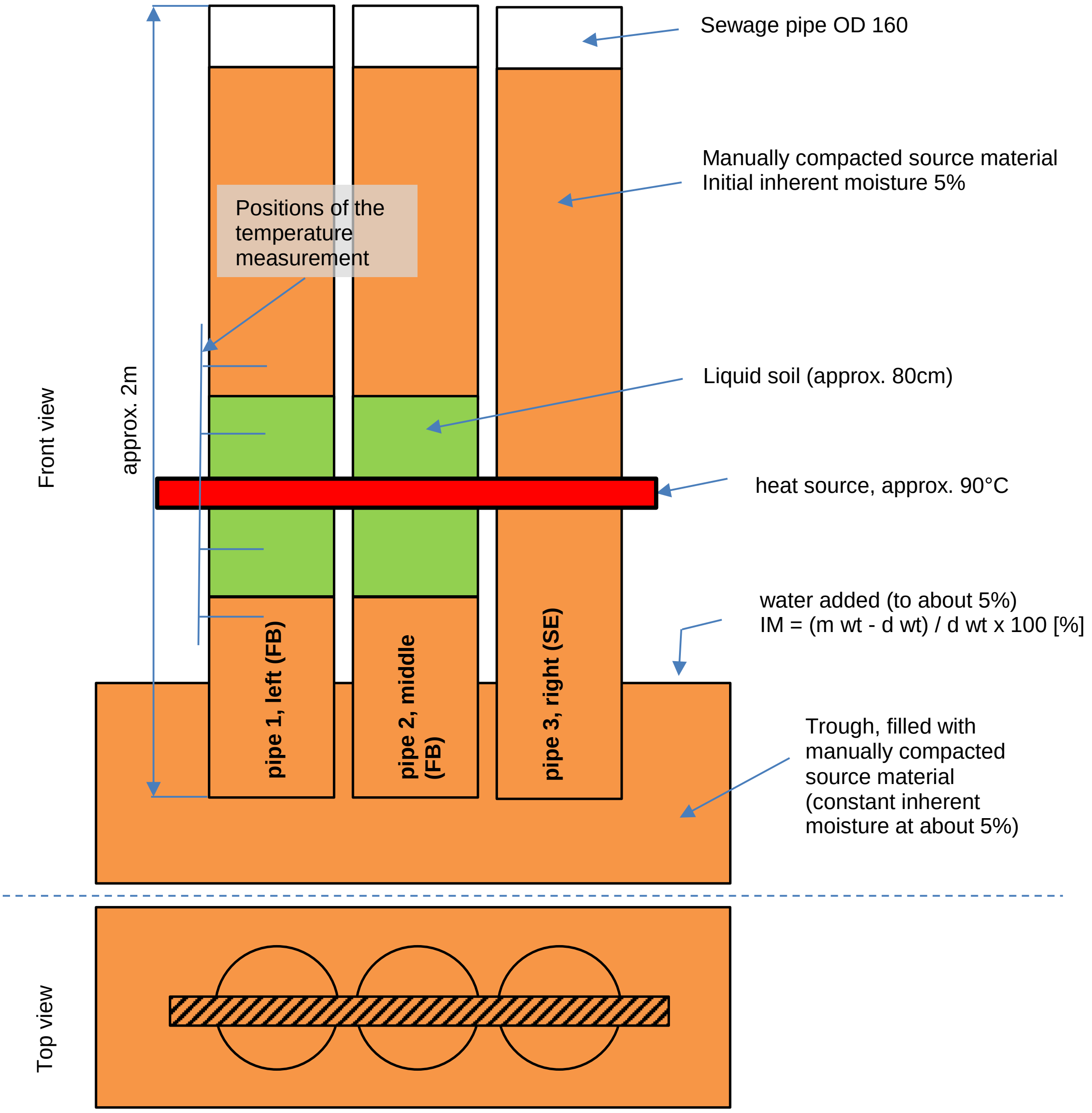


Figure 1: Draft of the test set-up

To keep the inherent moisture, ie the available water for the liquid soil, on a constant level, the inherent moisture of the source material is controlled via the mortar trough the pipes are based in.

The inherent moisture of the source material in the trough is checked in defined intervals, and if necessary water is added to keep it constant at a minimal inherent moisture of 5%.

 Assembly: bracing	 Connection of the heat source	 Overview test set-up
 Placing and manual compaction of material in the mortar trough	 Placing the pipes in the trough	 Digital Heating Controller
 Manual compaction of SE in the pipe	 RSS Flüssigboden in the sewage pipe	 Backfilling of the upper layer of SE

Figure 2: Photo documentation of the test set-up

3. Test dimensions

For the dimensioning of the test, we restricted the test set-up to the prevailing dimensions of a trench for tubes/pipes or cables in terms of the structure of the soil layers. In order to measure the actual fill levels of liquid soil, the sewage pipes were opened with an angle grinder after the end of the test (figure 3), and sealed again air-tight.

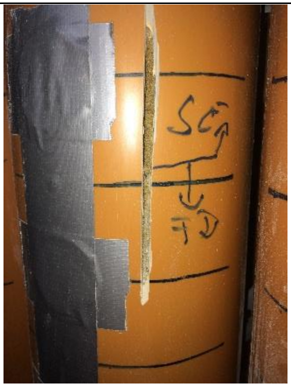
 Pipe_left_top	 Pipe_middle_top
 Pipe_left_bottom	 Pipe_middle_bottom

Figure 3: Lines/transitions between sand SE and liquid soil

Sand in the mortar trough:
Hight: 20cm
Width x Depth (top): 62cm x 36cm
Width x Depth (bottom): 57cm x 31cm

"pipe 1, left (FB)"
Thickness RSS Flüssigboden TS: 80cm
RSS Flüssigboden TS: Distance centre heat source (zero position) to the bottom: 33cm

RSS Flüssigboden TS: Distance centre heat source (zero position) to the top: 47cm

Distance centre heat source to the sand surface in the trough: 70cm

Hight sand over RSS Flüssigboden TS: 70cm

Insert depth sewage pipe in the sand in the trough: 11cm

"pipe 2, middle (FB)"

Thickness RSS Flüssigboden TS: 81cm

RSS Flüssigboden TS: Distance centre heat source (zero position) to the bottom: 35cm

RSS Flüssigboden TS: Distance centre heat source (zero position) to the top: 46cm

Distance centre heat source to the sand surface in the trough: 70cm

Hight sand over RSS Flüssigboden TS: 71cm

Insert depth sewage pipe in the sand in the trough: 11cm

"pipe 3, right (SE)"

Hight sand over RSS Flüssigboden TS: 186cm

Insert depth sewage pipe in the sand in the trough: 11cm

4. Base material

The source material for this test is a uniform-graded quartz sand. From this quartz sand, and a suitable cement (regarding its hydration process and reactivity), RSS FBC TS, and water, RSS Flüssigboden TS is produced according to a defined method.

Source material SE

Base material SE

Grain size distribution of the base material from dry sieving

Figure 4: Source material SE

The bedding and reference materials for the RSS Flüssigboden TS are also the same base material. Sand was selected as source material as we presumed the very weak binding forces for water adsorption of uniform-graded sand to be suitable to simulate a worst-case scenario.

The capillary forces that draw in water from the sand in the trough should as weak as possible. The natural inherent moisture of the sand is rather low compared to other soil types.

4.1. **RSS Flüssigboden TS – production**

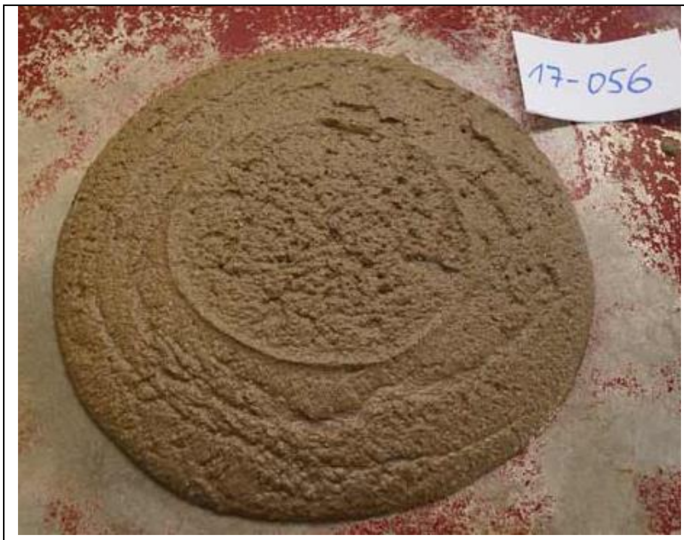
In the test, a mix design was applied that proved functional according to our long-term experience with this base material. The following target values of the liquid soil to be produced according to the selected mix design, are specified: load capacity (EV_2) > 45MN/m², unconfined compressive strength q_u = 0,1–0,3N/mm² , heat conductivity > 1,5W/m*K.

As a typical diameter of flow and as technologically relevant target value, 55cm were specified (figure 5). To reduce costs, we decided to refrain from additional external measurements of heat conductivity, frictional forces, and load capacity. If needed, these tests can be conducted later on. Cement CEM I, 42.5 R was applied as an accelerator typical for this purpose.

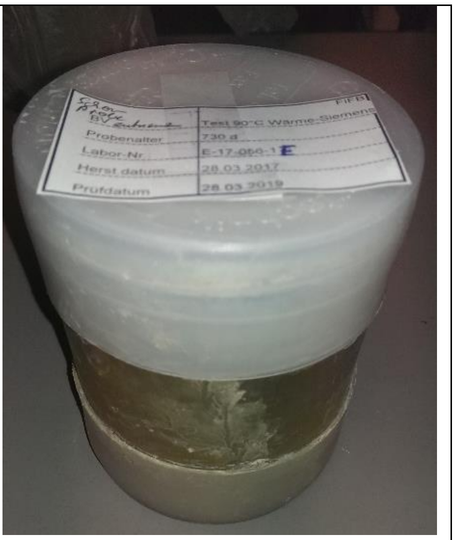
Table 1: Mix design data of the utilized Flüssigboden

Base material / dry	1535kg/m³
RSS FBC-TS	typical for the mix design
BCE: CEM I 42,5 R	typical for the mix design
Total water (incl. inherent moisture)	391 kg/m³
Diameter of flow	55cm

The selected type of Compound is a type required for a maximum heat dissipation: FBC-TS 3. The RSS Flüssigboden TS was produced manually with a Collo Mix stirrer. When we placed the RSS Flüssigboden TS in the pipes, at the same time, we placed RSS Flüssigboden TS in our standard core cutters with plastic sealing caps (height 120mm, inner diameter 96mm) (figure 5). The samples are stored, as usual, sealed air-tight at room temperature between 20–22°C.



Diameter of flow RSS Flüssigboden



Sample storage, comparative sample

Figure 5: Diameter of flow and storage cylinder

After the end of the test, the inherent moisture of the RSS Flüssigboden TS was examined in both the pipe samples and in the samples from the core cutters. The results will be compared and evaluated.

IM [%] = (moist wt - dry wt) / dry wt x 100%

The liquid soil is desiccated in a drying oven at 105°C for 24 hours.

Figure 6: Formula determination of inherent moisture

5. Cyclical temperature profile on the measuring probe (heating temperature of the heat source):

The heat source was coated by a 60cm long ¾ inch galvanised steel tube. In the steel tube, a 61cm glass fibre heating tape (HT95508) was inserted, and continually heated by a MC810B Digital Heating Controller. The temperature sensor was placed in the position "pipe 1, left (FB)" in the middle inside the steel tube.

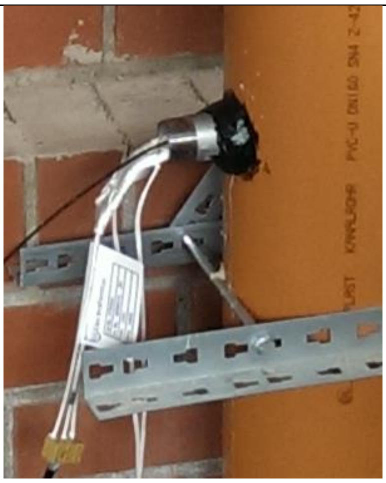
 Connection of the heat source	 Detail connection of the heat source, still without construction steel in the steel tube	 Temperature Controller, still without construction steel in the steel tube Heating off (lamp off), nevertheless, the temperature is still rising.

Figure 7: Photo documentation of the temperature control

The target temperature on the temperature sensor was 90°C. Due to the hysteresis of the heat source control, the area around the measuring sensor has heated to 94°C at the beginning of the test. When it reached 77°C, the heat source started heating again. This cycle of heating up and cooling down was optimised on 11 May 2017, see recording.

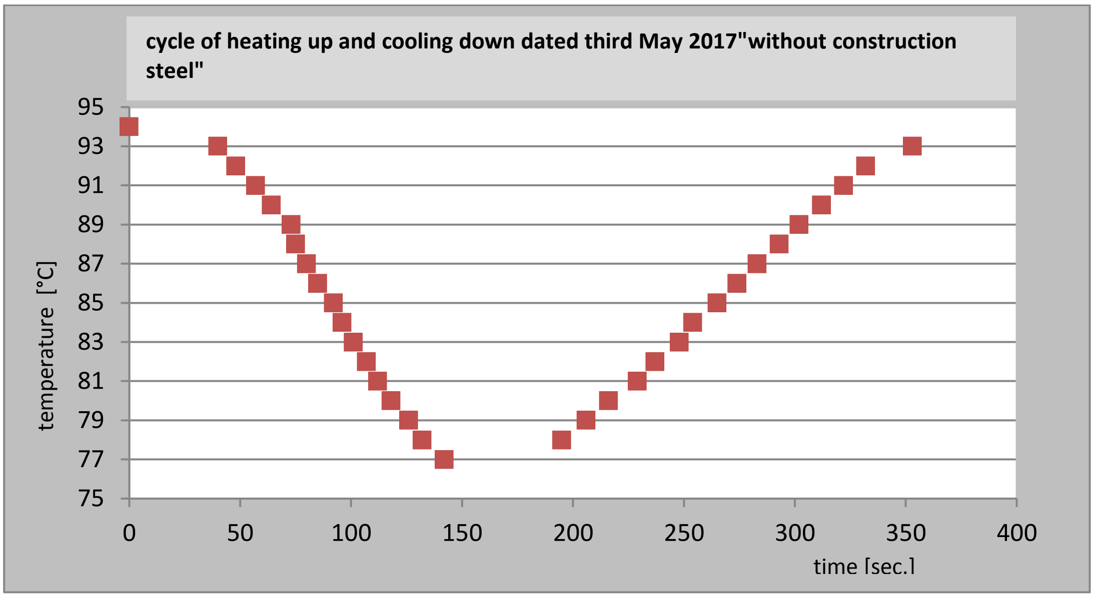


Figure 8: Temperature cycle on the temperature sensor of the heat source

The construction steel placed in the ¾ inch steel tube with a slight contact pressure on the heating tape optimised the heating cycle. The switching hysteresis on the temperature sensor was then between 83°C and 89°C, measured on 11 May 2017 and 12 May 2017.

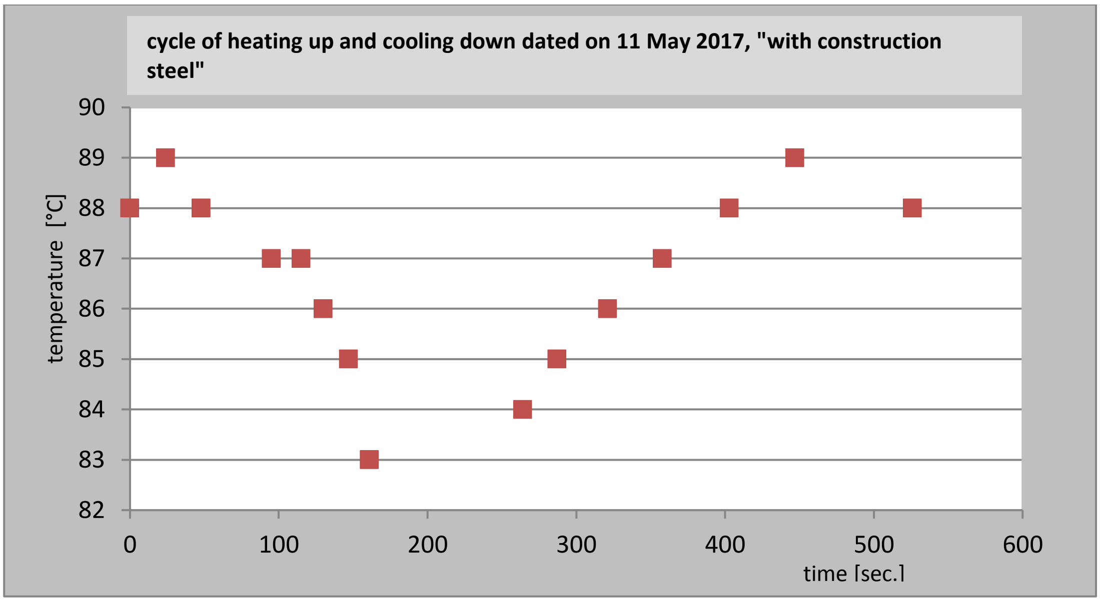


Figure 9: optimised temperature cycle on the temperature sensor of the heat source on 11 May 2017

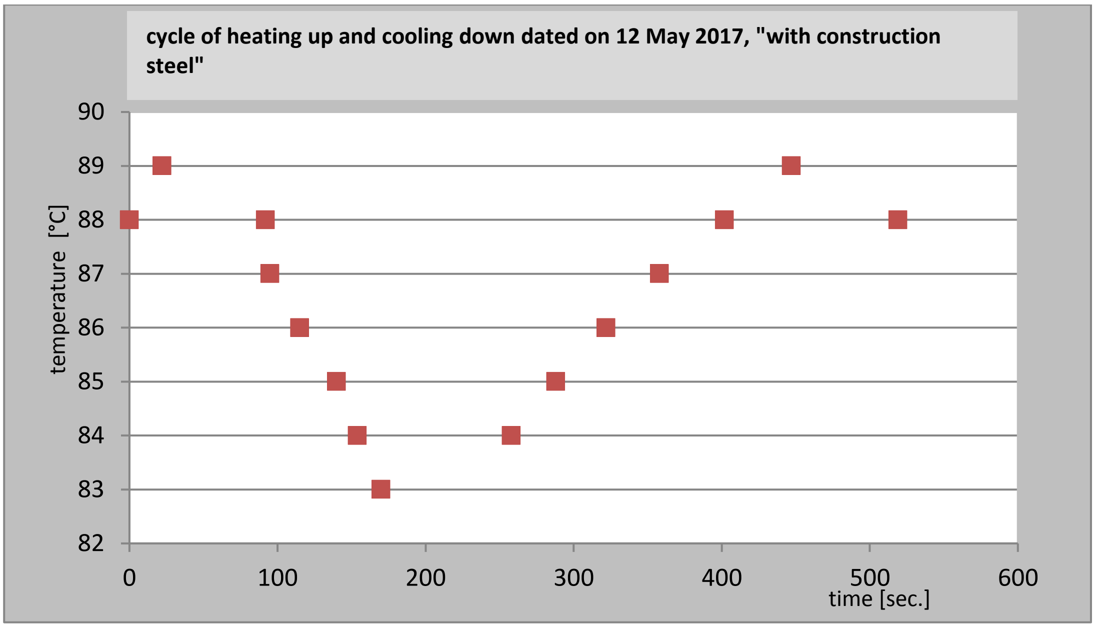


Figure 10: optimised temperature cycle on the temperature sensor of the heat source on 12 May 2017

6. Temperature profile (tube surface):

Despite the influence of the poor heat conductivity of the sewage pipes, the surface temperature of the pipes was measured several times in defined positions (figure 11). The applied measuring tool was the LTM 413 infra-red temperature measurement device. The selected distance between the pipes was 30cm. The position of the heat source is position 0 for each sewage pipe. Measurement positions below position 0 have negative signs, measurement positions above have positive signs.

Figure 11: Measuring principle surface temperature on the sewage pipes

The measurement results on the measurement positions on the pipe surface do not mirror the temperatures in the sand or in the RSS Flüssigboden TS. The influence of changes in the outside temperature and heterogeneous cooling effects caused by the contact to the ground on the bottom ends of the pipes are significant and are logged for the documentation. The temperature on the surfaces of the pipes was measured particularly in order to find differences between RSS Flüssigboden TS and sand, and to detect unexpected events. A thermal imaging camera was applied to visualise the surface temperatures (figures 18 and 24).

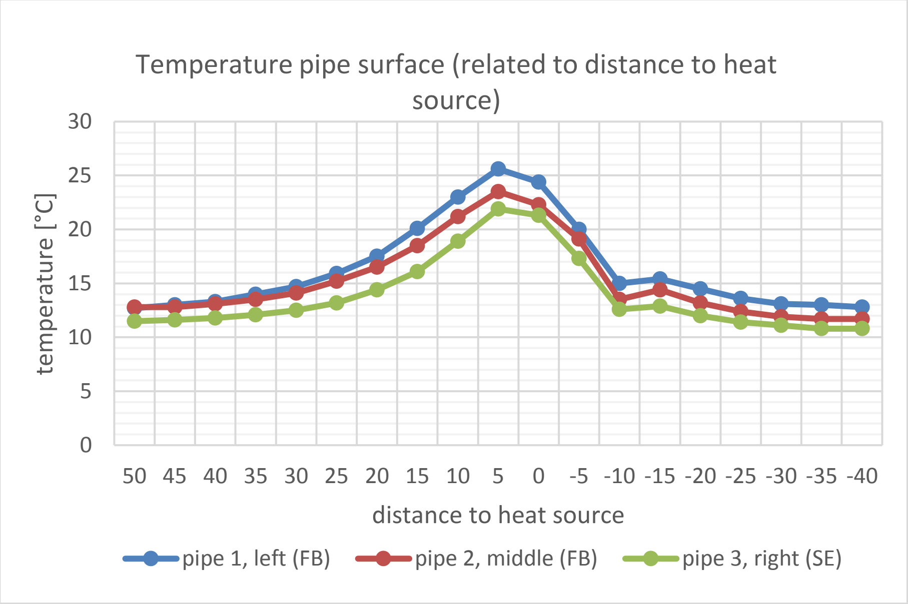


Figure 12: 08/05/2017 surface temperature (pipe), air temperature: 10.6°C

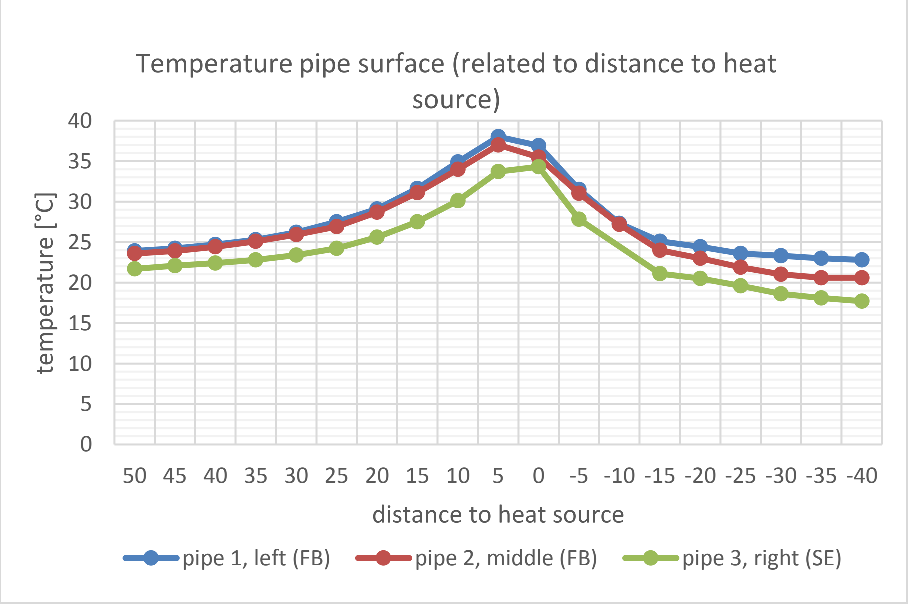


Figure 13: 17/05/2017 surface temperature (pipe), air temperature: 20°C

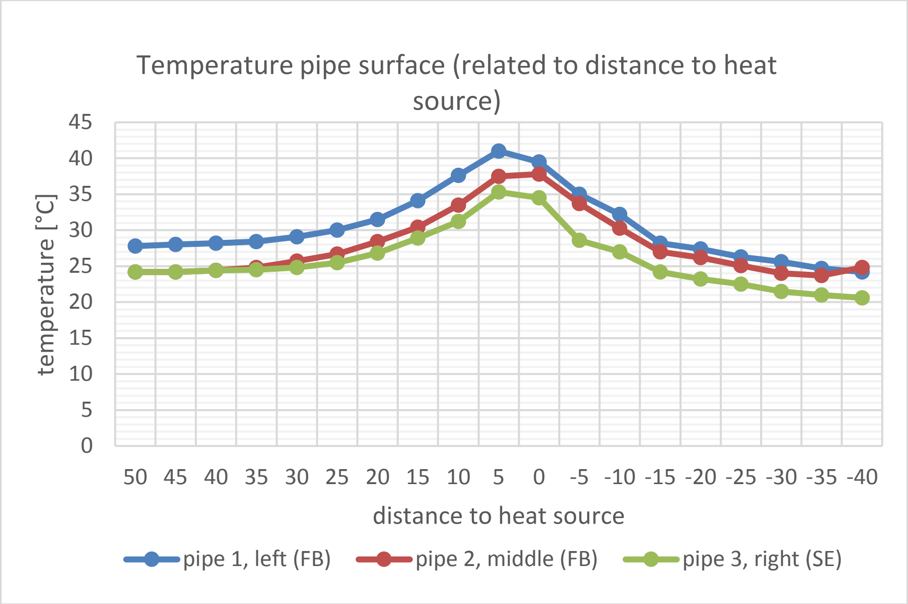


Figure 14: 23/05/2017 surface temperature (pipe), air temperature: 22.4°C

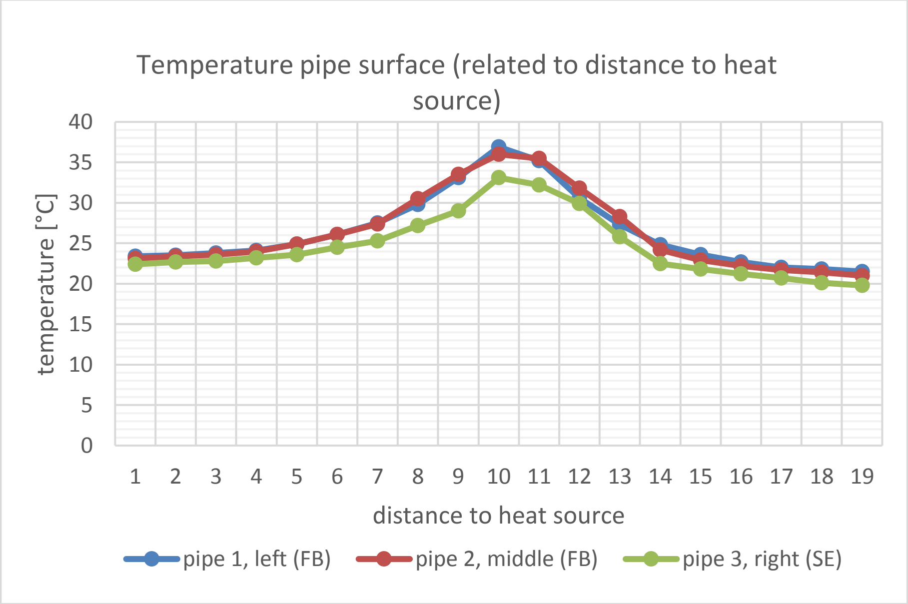


Figure 15: 31/05/2017 surface temperature (pipe), air temperature: 23.2°C

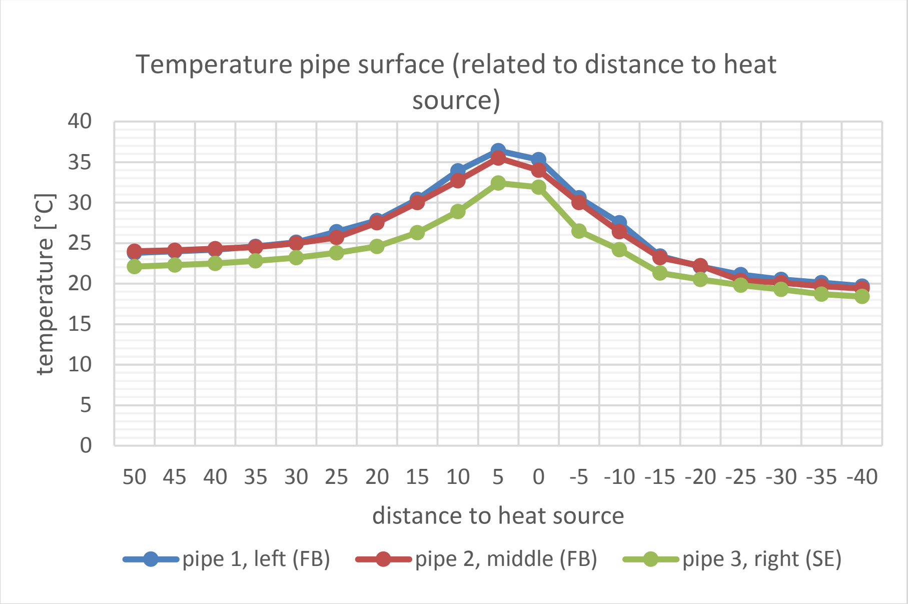


Figure 16: 08/06/2017 surface temperature (pipe), air temperature: 23°C

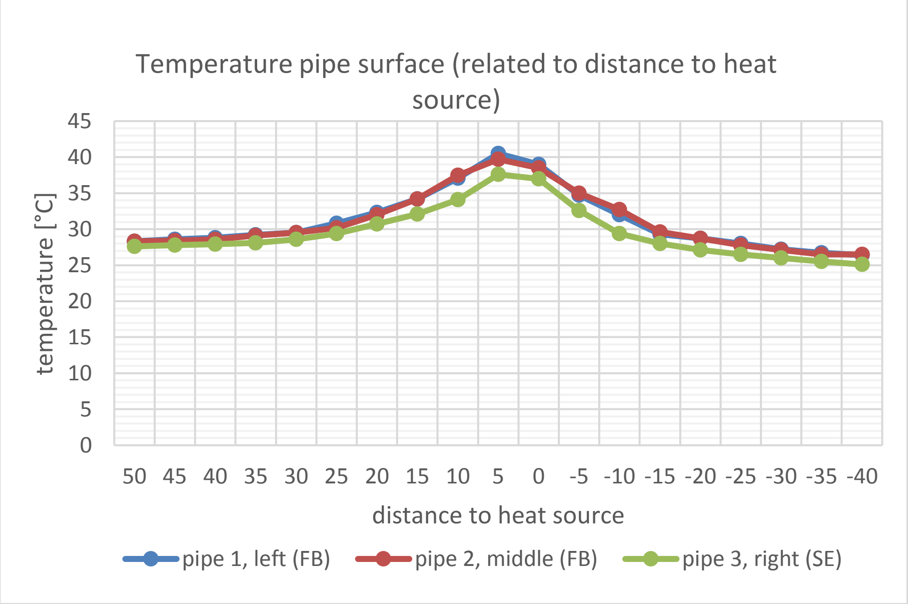
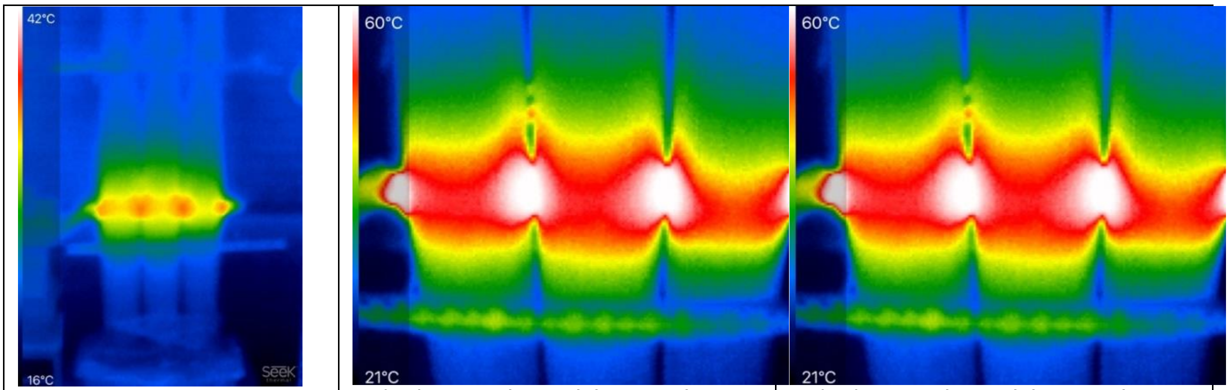


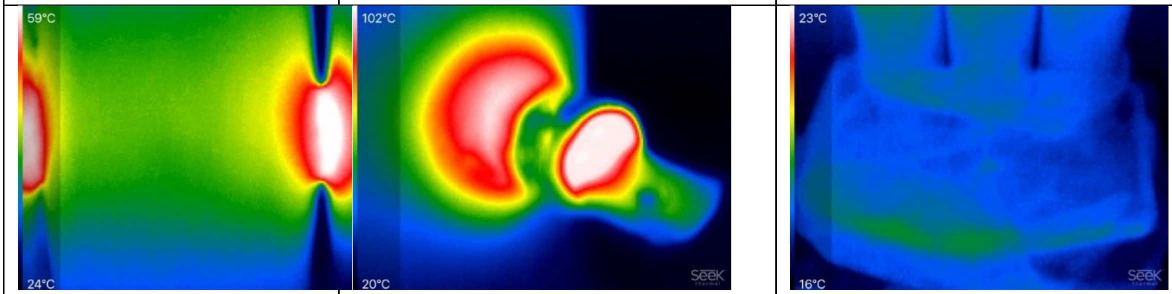
Figure 17: 12/06/2017 surface temperature (pipe), air temperature: 23.6°C



12/06/2017: Thermal image overview

12/06/2017: Thermal image close to heat source

12/06/2017: Thermal image close to heat source



12/06/2017: Thermal image detail

12/06/2017: Thermal image detail connection heat source, sand

12/06/2017: Thermal image detail trough sand

Figure 18: Thermal images test exterior side of pipe (12 June 2017) measured with Seek Compact Thermal Imaging Camera

7. Inherent moisture source material in trough

The inherent moisture of the tamped source material in the mortar trough was subject to slight variations, see table 2. We refrained from mixing the soil complete in order to determine the inherent moisture exactly. Instead, we took samples close to the surface and when the surface started to become dry, we moistened it with a spray bottle. The soil was covered with foil during the test. As we determined the inherent moisture only close to the surface, the manually compacted soil structure remained as undisturbed as possible.

Table 2: Test values control of the inherent moisture using a mortar trough

Date	Inherent moisture [%]
03/04/2017	4.5
18/04/2017	6.4
28/04/2017	5.7
04/05/2017	6.2
12/05/2017	6.1
19/05/2017	5.95
26/05/2017	5.0
31/05/2017	6.6
08/06/2017	6.3
12/06/2017	6.64
20/06/2017	6.72

8. Inherent moisture covering material on RSS Flüssigboden TS

The inherent moisture of sand covering the RSS Flüssigboden TS was measured periodically. On 28 March 2017, the inherent moisture was 5%. Until the end of the test (14 June 2017), the inherent moisture declined significantly, see documentation. The sample for the determination of the inherent moisture was taken close to the surface. We refrained from determining the exact depth from where the sample was taken.

Figure 19: Top view on the test set-up (determination of inherent moisture in covering sand over Flüssigboden/sand)

Table 3: Inherent moisture on the top ends of the pipes in the test set-up

Date	Inherent moisture in covering sand pipe 1, left (FB) [%]	Inherent moisture in covering sand pipe 2, middle (FB) [%]	Inherent moisture in upper pipe section pipe 3, right (SE) [%]
28/03/2017	5	5	5
14/06/2017	0.54	0.63	0.27

9. Deconstruction

On 14 June 2017, the specimens (pipes) were destroyed and samples were collected to determine the inherent moisture, and the temperature was measured directly in the sand and in the RSS Flüssigboden TS. Already during the deconstruction, it was noticeable that the RSS Flüssigboden TS had an inherent moisture level "typical" for RSS Flüssigboden TS. We did not notice any differences in moisture or heterogeneities.

 Deconstruction: Holes drilled for measuring the temperature.	 Deconstruction: Temperature measurement	 Deconstruction: Coring for sample collection inherent moisture
 Deconstruction: Coring for sample collection inherent moisture	 Deconstruction: Sample collection inherent moisture	 Deconstruction: Sample collection FB (still wet) detail

Figure 20: Deconstruction photo documentation (14 June 2017)

When we opened the pipe with the sand (pipe 3 right SE), however, we found very different moisture levels. In the zone close to the heat source, the colour of the sand was significantly lighter (figure 21). The desiccation was visible and could be felt manually. In the core holes in the next layers directly below and above the heat source, no desiccation was noticeable. Directly after the sample collection, the samples were weighed and dried.

Deconstruction: Sample collection

Sample collection: Flüssigboden (wet)

Deconstruction: Sample collection detail: sand on heat source (desiccated)

Figure 21: Deconstruction photo documentation (14 June 2017)

After the sample collection and the measurement of the inherent moisture, the holes were sealed with duct tape.

The test was run until 19 June 20017. On 19 June 2017, the last thermal images were taken with the holes unsealed, and the materials were evaluated visually. What was particularly noticeable was the condensed water on the duct tape that covered the holes over the RSS Flüssigboden TS. It resulted from the condensation of the air moisture on the thermal bridges (tape over holes).

 Samples "pipes with RSS Flüssigboden"	 Samples "pipe with sand"	 Samples "pipe with sand" detail
 Holes in the pipes for the collection of the samples left + middle Flüssigboden, right sand	 Image close to the heat source in the humid liquid soil	 Image close to the heat source in the sand "desiccated material"

Figure 22: Deconstruction 14 June 2017 photo documentation optical desiccation sand/moist condition Flüssigboden

 19/06/2017: Core holes in Flüssigboden with condensed water.	 19/06/2017: Core holes in Flüssigboden and in sand

Figure 23: Continuation of the test until 19 June 2017 with sealed holes

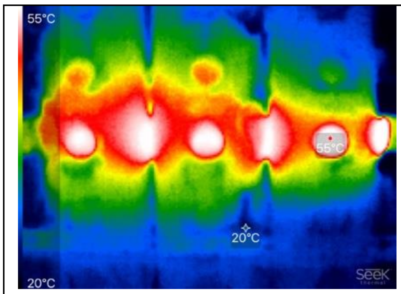
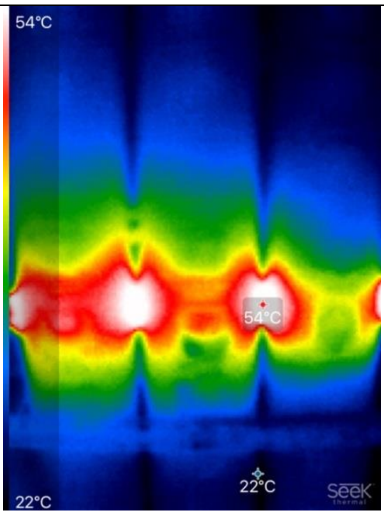
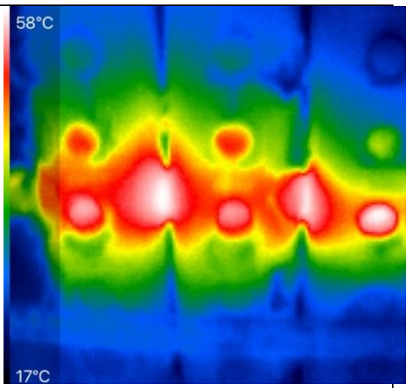
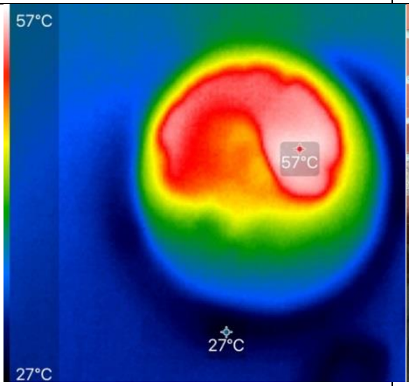
 19/06/2017: Thermal image with core hole	 19/06/2017: Thermal image with core hole	 19/06/2017: Thermal image with core hole
 19/06/2017: Thermal image core hole detail	 19/06/2017 deconstruction	 19/06/2017 deconstruction

Figure 24: Thermal images with photos, 19/06/2017 and deconstruction

10. RSS Flüssigboden TS – test data based on DIN 18136

Four samples had been taken from the RSS Flüssigboden TS produced for filling the pipes, and stored at room temperature, to determine the unconfined compressive strength and the inherent moisture. The soil mechanical parameters were determined based on DIN 18136.

Derogations from standard DIN 18136

By derogation from the requirements of the DIN paragraph 6.1 "Form and Measures"

> *Their hight is supposed to be between 2 and 2.5 times the diameter or the edge length. Derogations must be indicated and justified*

the indicated measures of the utilized samples were chosen.
By derogation from the requirements of the DIN paragraph 9 "Indication of the Results"

> *b) Soil type according to DIN 4022-1*
> *c) quality class of the sample according to DIN 4021*

Soil type: not defined for Flüssigboden
Quality classes: no sample collection but sample production

In the course of the preparation of the test, the measures (diameter and hight) of the samples were determined. The samples were put into a testing machine (press) UP 25/50. The samples were tested with a constant deformation speed of 0.25mm/min. The uniaxial compressive strength was measured at the respective test force. The uniaxial compressive strength q_u was determined as maximum compressive stress. We determine the unconfined E-modulus Eu as the maximum slope of the tangent of the stress–strain curve, E_U30 as 30% of the strain at failure, and E_U50 as 50% of the strain at failure.

After the end of the test, the water content and the density of the samples were determined.

Table 4: Test data on the placed Flüssigboden (stored in core cutters at room temperature)

Sample	Age [d]	q_u [N/mm²]	E_U[*1] [MN/m²]	E_{U50} [MN/m²]	E_{U30} [MN/m²]	Strain at failure [%]	Mass [g]
17-056 a	28	0.21	11.70	8.70	10.30	3.01	1680.00
17-056 b	28	0.20	14.50	12.00	12.70	2.81	1695.00
17-056 c	78	Here only determination of the inherent moisture on the day when the test was terminated					
17-056 d	28	Planned test date: 28/03/2019					

Sample	Initial height ha [mm]	Initial Ø da [mm]	Volume [cm³]	Bulk density [kg/dm³]	Moisture content [%]
17-056 a	120	96	868.6	1.93	22.57
17-056 b	120	96	868.6	1.95	23.39
17-056 c			868.6	1.94	23.97
17-056 d	Planned test date: 28/03/2019				

[*1] E_U = max dσ/dε modulus of the unconfined compression test at maximum slope of the tangent of the stress–strain curve with $\varepsilon = \Delta h/h_a$,

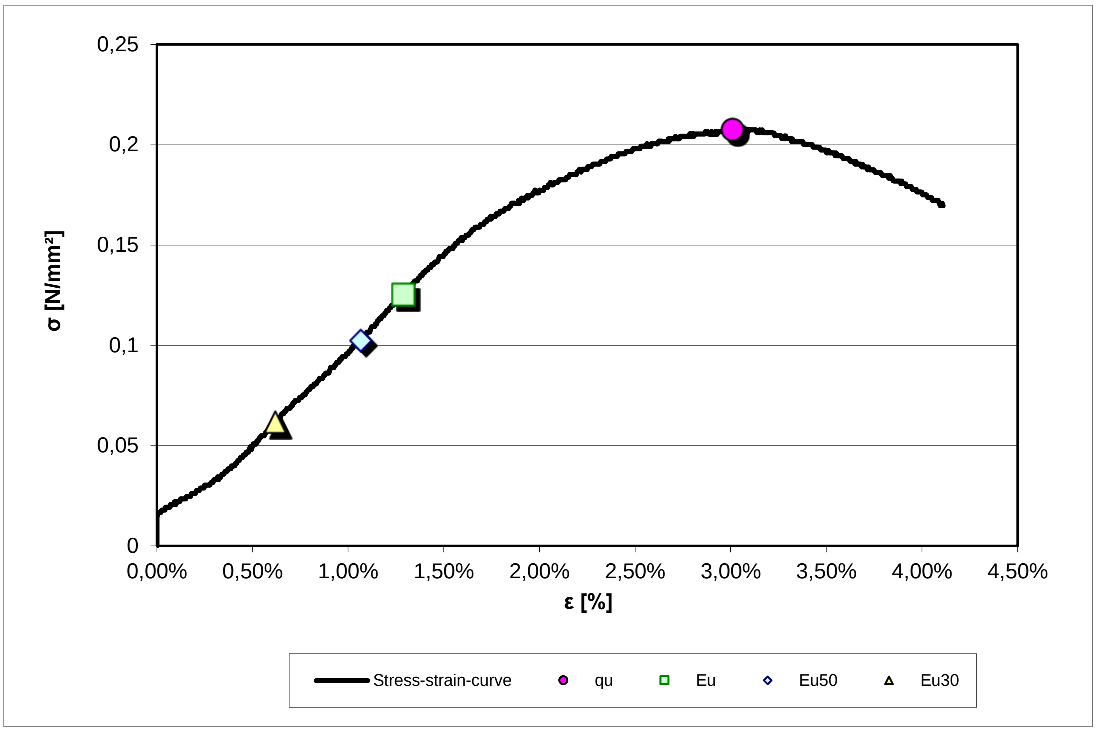


Figure 25: Stress-strain-curve sample 17-056 a

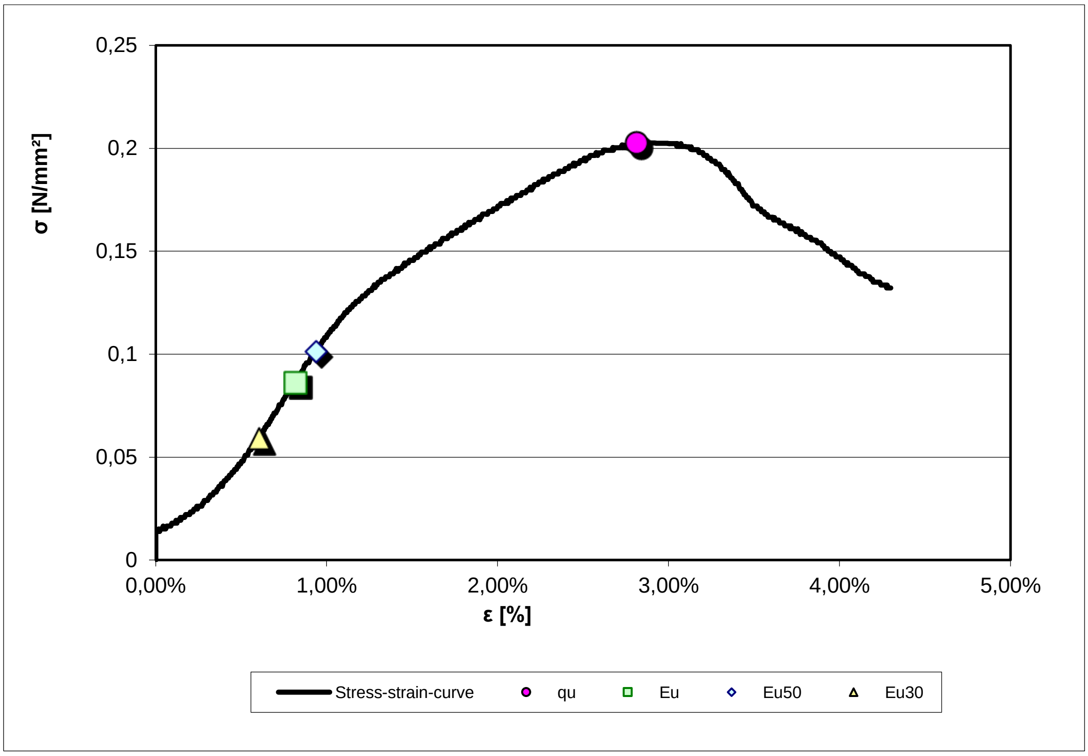


Figure 26: Stress-strain-curve sample 17-056 b

11. Evaluation:

11.1. Surface temperature of the test containers (plastic pipes)

The temperatures measured on the exterior surfaces of the pipes (figures 12–17) show their maximum in the zone between 3–5cm above the heat source (position 0), and so they mirror the natural physical behaviour of thermal processes. The surface temperatures of the pipes in the zones filled with RSS Flüssigboden TS are always higher than the zones filled with sand.

This circumstance results from the better heat dissipation of RSS Flüssigboden TS compared with sand – the latter starts to develop an insulating effect during the desiccation process. The temperature profiles are not mirrored above and below position 0 (heat source). The zones in the lower half are significantly cooler than in the upper half.

The reason could be a cooling effect caused by soil contact (here the material in the trough) which acts as a kind of "cold storage".

Other possible reasons cannot be examined at this time. For further test series, it might make sense to insulate the trough in order to control the inherent moisture on the ground. To prevent evaporation to a large extent a vapour barrier on the trough could be applied.

Yet, the chosen test set-up appears to a good model of the soil layers underneath ultra-high voltage transmission lines, exactly because of the evaporation effect and the soil moisture kept constant.

The thermal images (figures 18 and 24) confirm the higher temperatures on the surfaces of the pipes (pipe 1 and 2) in the zones filled with RSS Flüssigboden TS compared with the zones filled with sand, and therefore they confirm that RSS Flüssigboden TS dissipates the heat better.

The pictures show also thermal bridges due to metal fixing elements and in the lower zones of the trough simulating the subsoil. These thermal bridges, though, do not play a significant role in the total evaluation of the occurring temperatures in the established equilibrium state.

11.2. Temperature in RSS Flüssigboden TS/sand

On 14 June 2017, the pipes were opened mechanically (figure 20) in order to measure the temperature in the RSS Flüssigboden TS and in the sand, and to take samples for the determination of the inherent moisture. To measure the temperature, 4mm bore holes were made at intervals of 5cm. The temperature sensor was placed always at a depth of 2cm in the liquid soil. The measurement results (figure 27) show that the RSS Flüssigboden TS has almost identical temperatures in comparable measuring positions.

The temperatures in the RSS Flüssigboden TS are each higher than the temperatures in the sand in comparable measuring positions. The reason for that is the better heat conductivity of RSS Flüssigboden TS compared to sand, as for the measured surface temperatures.

The maximum temperatures are now measured in the zone of the heat source (position 0). Unlike in the temperature measurements on the surfaces of the pipes, the temperature–pipe distance curve (figure 27) for RSS Flüssigboden TS can more likely be mirrored. The sand shows a bigger temperature loss towards the trough, as for the measured surface temperatures. The influence of the distance to the trough is smaller for the RSS Flüssigboden than for the sand. This effect can also be explained with the different properties of RSS Flüssigboden TS compared to sand: Desiccating sand shows a suction behaviour, connected with the respective substantial and energetic exchange processes, whereas the zones filled with RSS Flüssigboden TS do not desiccate to a relevant extent and so do not show such behaviour and processes.

The temperature transition between RSS Flüssigboden TS and sand in pipes 1 and 2 doesn't seem to be characteristic. This is probably due to the already small temperature differences in the transition zone RSS Flüssigboden TS–sand.

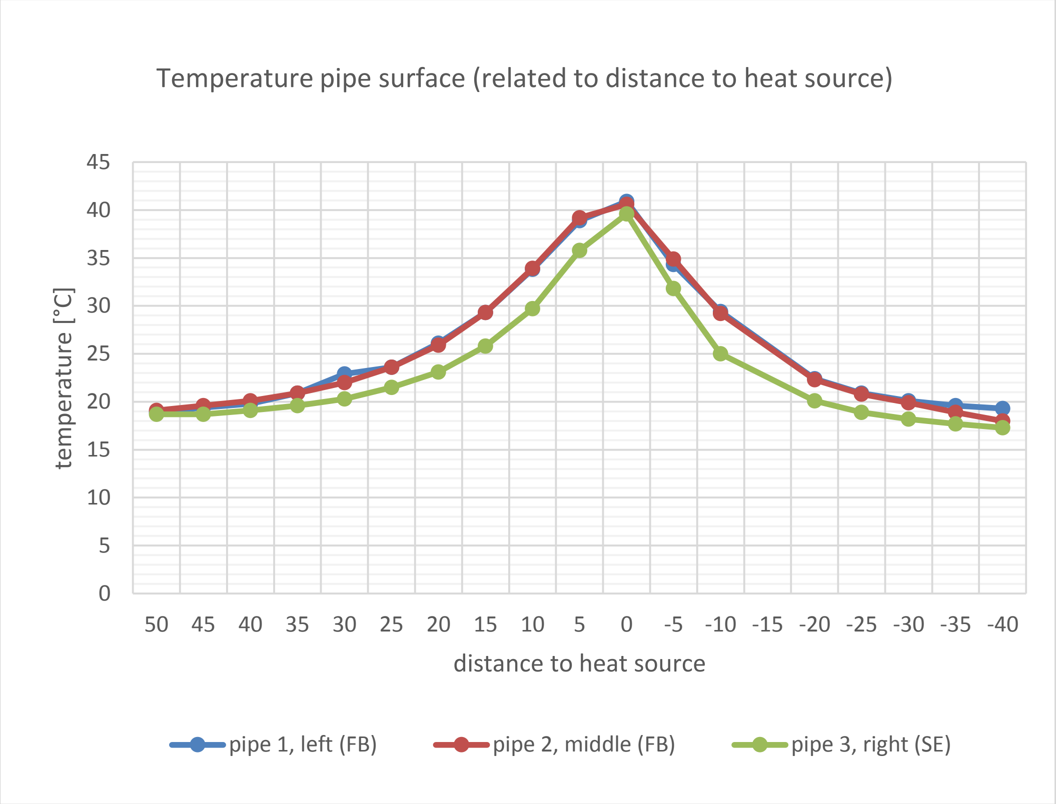


Figure 27: Deconstruction (14 June 2017) temperature measurement points (in core holes) measuring probe 2cm in the FB before pipe edge.

The thermal images (figure 24) of 19 June 2017 confirm the better heat dissipation of RSS Flüssigboden TS compared with the used sand also visually. This is visible especially in the zones of the holes for sample collection. In the zones of the holes the heat source is largely bare, so the temperatures shown on the thermal images are the same, whereas the zones covered with RSS Flüssigboden TS or sand show very different temperatures.

11.3. **Inherent moisture in RSS Flüssigboden TS/sand**

On 14 June 2017, the pipes were opened mechanically in order to take samples to determine the inherent moisture (figures 20–22). To take samples, 44mm core holes of 4–6cm depth were bored. The samples taken in the holes were immediately weighed and their inherent moisture was determined. The distances between the core holes were 10cm.

Figure 28 shows the inherent moisture of the samples of RSS Flüssigboden TS and sand with the distances to the heat source after permanent heating to about 90°C for 47 days. RSS Flüssigboden TS shows rather constant values of inherent moisture. Compared to the sample stored in a core cutter at room temperature (E-17-056 c) the RSS Flüssigboden TS samples from the permanently heated zones of the pipe has an only slightly lower inherent moisture

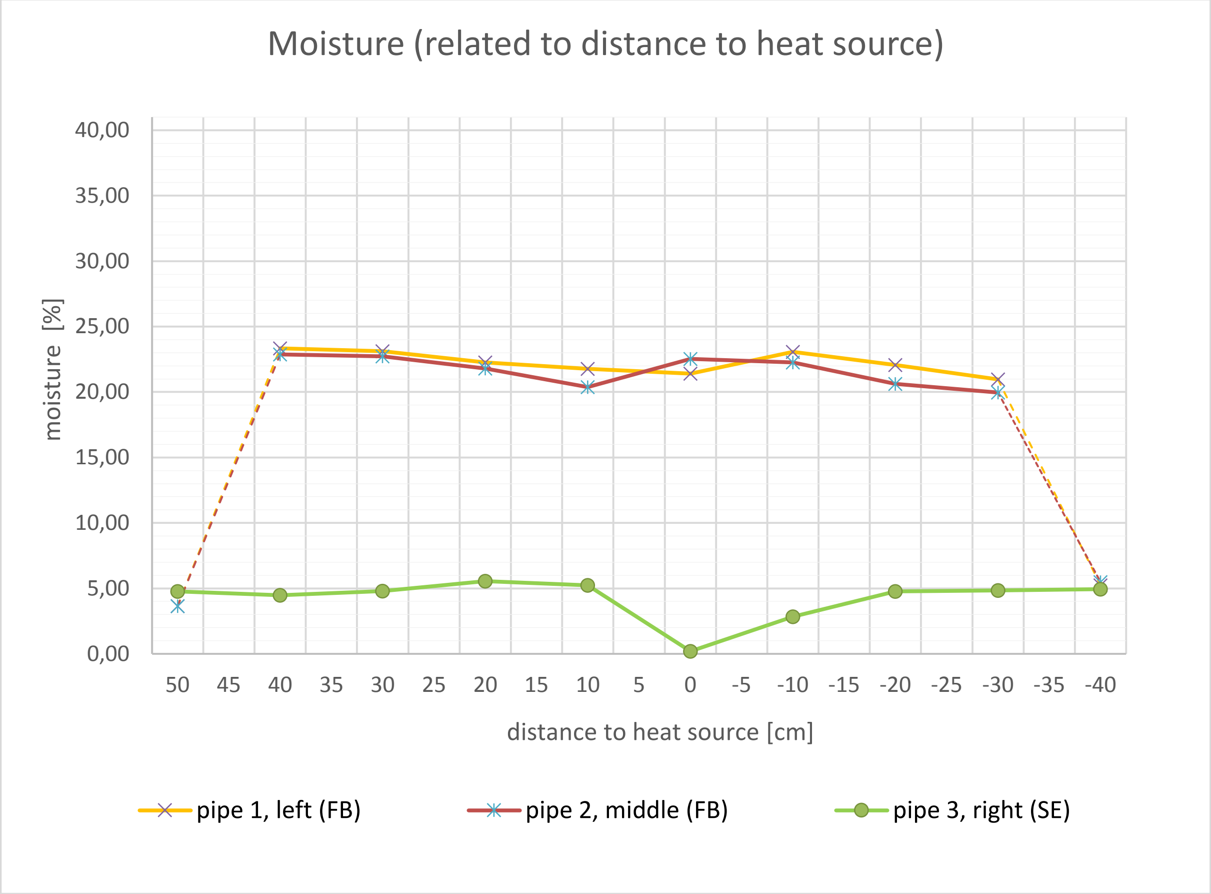


Figure 28: Deconstruction (14 June 2017) inherent moisture core samples

Table 5: Data inherent moisture core samples; deconstruction (14 June 2017)

distance pipe [cm]	Inherent moisture pipe 1 (FB) [%]	Inherent moisture pipe 2 (FB) [%]	Inherent moisture pipe 3 (SE) [%]	Material
50	3.65	3.64	4.77	SE
40	**23.33**	**22.87**	4.48	RSS FB TS
30	**23.12**	**22.72**	4.78	RSS FB TS
20	**22.25**	**21.80**	5.54	RSS FB TS
10	**21.78**	**20.37**	5.24	RSS FB TS
0	**21.40**	**22.53**	0.20	RSS FB TS
-10	**23.08**	**22.27**	2.84	RSS FB TS
-20	**22.06**	**20.63**	4.76	RSS FB TS
-30	**20.96**	**19.97**	4.84	RSS FB TS
-40	5.48	5.48	4.94	SE

The sewage pipe filled with sand shows significant desiccation in the zone around the heat source after being heated to about 90°C for 47 days. Above the heat source the desiccated zone is between 0 and 10cm, under the heat source it is between 15 and 20cm.

Deconstruction: 19 June 2017, sand in position 0 – dry and in positions -1 and +1 wet

Figure 29: Photo with holes – dry sand in the zone around the heat source bedding and visually still wet sand 10cm each under and above the bedding zone

This makes clear that particularly the critical zones of the contact surfaces between heat source and sand are a problem for the heat transfer, as the consequences of the desiccation occur here first and hinder heat dissipation. The desiccation, and, connected with that, the loss of the capillary cohesion effect lead to the formation of an annular gap between heat source and sand, and thus the heat transfer decreases, as in the zone of the annular gap an additional heat transfer resistance develops. The consequences of sand as bedding material can be measured; they can be higher temperatures occurring in the components emitting heat (eg GIL tubes or cables) compared with RSS Flüssigboden TS.

The presented test evaluation results of the temperature profiles confirm the results from the measurements of Amprion in the course of the test project "Osterrath". The results of the inherent moisture measurements additionally make clear why in the former and in the present project there is such a big difference between the measured temperatures occurring in the different bedding materials (ie thermally stabilizing RSS Flüssigboden TS or sand) of heat sources such as GIL tubes and cables.

For the practical set-up of ultra-high voltage transmission lines this means that it is absolutely necessary to consider not only the heat conductivity lambda [λ] but also the heat transfer resistances between the surface of the heat source (eg the surface of the GIL tubes or cables) and their changeability by taking advantage of the adjustable properties of RSS Flüssigboden TS in order to evaluate the heat dissipation that can actually be used with certainty.

Because of the fact that the heat transfer is correlated with the contact pressure between bedding material and heat source, the heat transfer resistances can be minimized in a targeted manner and so the heat dissipation can be improved effectively. This is expressed by the so-called contact coefficient K_k in [W/m²K]. It shows that a higher contact pressure of the bedding material leads to a better heat dissipation. In RSS Flüssigboden TS this contact pressure can be influenced in a targeted manner to a certain extent, and so can the heat conductivity, by adjusting the mix design. Different contact pressures and different heat conductivities set in RSS Flüssigboden TS can be determined by additional tests. These verifications were not part of the present test, as they are already part of the standard verifications for the specialized planning of ultra-high voltage transmission lines bedded in RSS Flüssigboden TS. Though, an additional test can be made on both the determination of different contact pressures and the examination of different soil types with heat conductivities adjusted by particular mix designs.

This is a good verification that shows that by manipulation of 2 factors of an equation of 3 factors (heat flux, also called thermal output $Q/t = \lambda \times A \times (T1-T2)/d$) planners of ultra-high voltage transmission lines gain the opportunity to **guarantee** sufficient heat dissipation for the safe operation also when using **soil types with inherent poor heat conductivity**.

RSS Flüssigboden TS proved very resistant against desiccation in the zones with contact with sand (contact zone 1+2 between +40cm and +50cm; contact zone 3+4 between -30cm and -

40cm). A further test on the detailed examination of the transition zone liquid soil–sand appears to make sense, as this could influence the planning of a typical cross section of ultra-high voltage transmission lines and thus has the potential to save costs.

Despite the high temperature of 90°C on the contact surface between heat source and RSS Flüssigboden TS, the zones around the heat source do not show any measurable desiccation, as the measurement data show.

These results also confirm the results from former R&D projects by Prof Rogler (HTW Dresden), our own results from the cooperation with Siemens and Prof Steffens (HS Regensburg), and the results from the in situ test project of Amprion in Osterath, as well as other realized projects.

What's new in the present test is the application of a heat source emitting 90°C permanently for 47 days, which corresponds to the the temperature on the contact surfaces between heat source and bedding material. In a realistic scenario the GIL tubes or cables represent the heat source with a surface temperature of 90°C.

It's also new that the applied test set-up made it possible for the first time to simulate real soil layers in terms of type and thickness, and that not only the measurement results were taken, but also the moisture of the bedding material was measured in samples taken from the different layers representing the different installation depths of the trench structure.

Another new element in this test was the comparison between measured soil moistures of samples from the pipes and reference sample produced from the same RSS Flüssigboden TS but stored aside. This confirmed the robustness of the measured results and provides the security needed for the practical application of the test results in the form of a plausibility check.

To sum up, it can be stated that:

- RSS Flüssigboden TS as bedding material does not desiccate under in sito conditions, and allows for safe operation of ultra-high voltage transmission lines, having the potential to reduce costs
- the statement above is also valid for extreme temperatures, if eg 90°C occurred on the contact surfaces
- it offers large safety reserves against overload or it allows to reduce cable cross sections or other materials

- it allows for other designs than the usual standard cross sections of cable routes
- also soils with poor heat conductivity can be used as bedding material improved by application of the liquid soil method
- these advantages can be used for other space-saving and diplomatic solutions in co-ordination with the land owners and users, and so eg the necessary space consumption can be reduced significantly
- in contrast to the results from RSS Flüssigboden TS, the sand applied as reference bedding material showed the usual desiccation behaviour
- the application of RSS Flüssigboden TS provides a series of further potentials for cost minimization, which can be exploited within the preceding planning process accompanying the soil examination

12. Overview test data

Table 6: Overview test data

Lab number Base material	Soil group base material	Mix design data						
		Soil dry [kg/m^3]	B-CE [kg/m^3]	B-CE type	FBC [kg/m^3]	FBC type	Total water [kg/m^3]	Diameter of flow [cm]
17-056	SE	1535	typical for the mix design	CEM I 42,5 R	typical for the mix design	TS	391	55

Lab number Reference sand	Soil group reference sand	Target values RSS Flüssigboden						
		Desiccation with temperature control	Heat conductivity	Temperature of the heat source	qu (28 d)	EV2 value	Surface friction	Diameter of flow [cm]
17-056	SE	minimum	maximum	90°C	[*3] 0,1-0,3 N/mm^2)	>45 MN/m^2	maximum	55

FB placement	Start temperature control 90°C	FB deconstruction	Temperature of the heat source	Average inherent moisture trough (SE)	Average qu after 28 d
28/03/2017	28/04/2017	14/06/2017	[*2] ca. 83-89°C	[*1] ca. 6 %	>0.21 N/mm^2

Average moisture content FB "pipe 1 FB left" heated to 90°C, 14 June 2017	Average moisture content FB "pipe 2 FB middle" heated to 90°C, 14 June 2017	Average moisture content FB storage at 20 °C, 14 June 2017
22.24%	21.65%	23.97%

[*1] Determination of inherent moisture only in the upper zone of the trough. It should be assumed that the average soil moisture in the mortar trough is lower.

[*2] Until 11 May 2017 temperature fluctuations 77°C–94°C, from 11 May 2017 on temperature fluctuations approx. 83°C–89°C

[*3] Typical soil value